UNIVERSITY OF
STIRLING

Management of Environmental Impacts of Gold Mining in Southern Ghana

By

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Submitted for the degree of
Doctor of Philosophy (Ph.D.)

January 2004

01/04

DEDICATION

This work is dedicated to my wife Margaret, who gave me immeasurable support when my academic journey was at a crossroads

ABSTRACT

Many environmental and socio-economic problems have been known to be associated with surface gold mining operations in southern Ghana over many years. In this study, these mining impacts are examined using four case study areas and linked to the type and scale of mining operations and the social and physical geography of each region. Information on mining impacts and adverse impact management was obtained from four mining companies, and 800 residents from 16 communities, in the study area using questionnaires, personal interviews and field observations. Additional information was also obtained from relevant government and other institutions. A critical assessment of the current status of the environment and socio-economic situation of, as well as environmental management measures pursued in, the four mining areas reveals that despite a number of prevailing problems, many mining impact mitigation measures are being pursued in the region. These measures are aimed at environmental protection and minimisation of socio-economic impacts of mining. However, common to most of the mines is the use of largely disjointed, and in some cases, *ad hoc* approaches in the design and implementation of environmental management programmes. A more co-ordinated and cohesive approach to managing mining impacts is required, to ensure environmentally sustainable and socially responsible mining in the region. The use of an Environmental Management System (EMS) is proposed. A community-centred framework based on the geo-environmental characteristics of the study area upon which such a system could be built is presented. This framework could be adopted or adapted for the development of a viable EMS for surface gold mining, which, in turn, would lead to environmentally and socially responsible mining in the study area in particular, and southern Ghana in general.

Key words

Surface Mining; Environmental Sustainability; Environmental Performance Assessment; Best Practice; Environmental Management System; ISO-14001 EMS Standard; Impact Mitigation; Remediation Measures; Community Perceptions; Pollution Control; Waste Management; Environmental Quality Monitoring.

ACKNOWLEDGEMENTS

I would like to thank Prof. Michael Thomas and Dr. David Gilvear, who, as my Research Supervisors, were helpful at every stage of this work. I am also grateful to Dr. Ian Moffatt (School of Biological and Environmental Sciences, University of Stirling) for his useful suggestions and advice at a very crucial stage of the research. I also thank Mr. George Anokye-Yeboah, Mr. Kennedy Oppong, Mrs. Esther Oppong, Mrs. Margaret Kyeremeh and WWF (Germany) for their financial support that made it possible for me to pursue this study. I am also thankful to Mr. Christian Holm (a former postgraduate [PhD] student of the School of Biological and Environmental Sciences – University of Stirling) for the vital role he played in securing financial support from WWF (Germany) for my research. The provision of funds for my fieldwork in Ghana by the Department of Environmental Science (University of Stirling) is also acknowledged with thanks.

I am greatly indebted to the four mining companies selected for this study, especially, their Environmental Management Departments, for their co-operation and support. My thanks also go to members of the sixteen communities selected for the socio-economic surveys, for the unstinting enthusiasm with which they responded to the study questionnaires and personal interviews. The 'Unit Committees' (Community Development Committees) of the sixteen communities are especially thanked for their outstanding co-operation during the focus group discussions.

I would also like to express my profoundest gratitude to staff of government and other institutions in Ghana (Environmental Protection Agency, Minerals Commission, Mines Department, Ghana Chamber of Mines, Western University College of Ghana, Geological Survey Department, Survey Department and the Water Resources Research Institute) who provided me with important information / data. I would also like to thank the following people for their advice on various aspects of the research:

- Prof. Daniel Mireku-Gyimah and Prof. Newton Amegbey – Western University College of Ghana (formerly Tarkwa School of Mines)
- Mr. Stephen Piedu – Mines Department, Tarkwa, Ghana
- Dr. Robert Joy and Mr. David Lee – Environment Protection Agency, Melbourne, Victoria
- Ms. Kate Howie – Department of Mathematics, University of Stirling, Scotland
- Mr. Fergus Anckorn – Knight Piésold Ltd., Ashford, UK
- Prof. Peter May – Murdoch University, Perth, Western Australia
- Mr. Chris Routh – Environmental Consultancy, University of Sheffield, UK
- Ms. Karen Dalgleish – Taylor Dalgleish Associates Ltd., Mineral Planning and Geological Consultants, Dunblane, Scotland

Several thanks also go to Mr Bill Jamieson for his invaluable help in the provision of support and advice on all the cartographic work in this thesis, and to Mr. John McArthur who was always ready to help solve all the technical problems with my Personal Computer throughout the research period.

DECLARATION

I hereby verify that the contents of this thesis are based on the results of my own work and have not been included in any other thesis. Where used, other sources are acknowledged in the text.

Samuel Kyeremeh

Stirling, January 2004

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CHAPTER ONE

INTRODUCTION

1.0 **Gold Mining Worldwide: Production, Impacts and Adverse Impact Management**

Gold is produced in many parts of the world, with South Africa being the world's largest producer of the metal. In 1997, globally, the top 15 gold producing companies produced a total of 1,054 tonnes (43% of global mine supply) (Gold Fields Mineral Services, 1998). Table 1.1 shows gold production by the top gold producing countries in the world for the years 1996 and 1997. Gold production by the top gold-producing companies in 1996 and 1997 is shown in Table 1.2.

Despite its economic importance to nations that produce it (Dickson & Benneh, 1988; Kesse, 1985), there is limited knowledge of the various adverse impacts associated with each of the processes in the production of gold. Impacts include water, air and soil pollution and the destruction of habitats of terrestrial and aquatic organisms (Korte & Coulston, 1998). Associated with many surface gold mining operations is environmental degradation, including a transformation of the physiography of the mined area – progression of spoil piles and pits extending for several kilometres (Orozco *et al*, 1993), waterlogging, accelerated runoff and soil erosion (Haigh, 1992). Of particular concern in areas where the ore body contains sulphide minerals is the issue of Acid Mine Drainage (AMD). AMD is produced when pyritic mine spoils – spoils containing sulphide-bearing minerals – decompose in the presence of water and oxygen (Nicholson, 1994) to produce sulphuric

Table 1.1: Gold Production by the Top Gold Producing Countries in the World – 1996 & 1997 (Gold Fields Mineral Services Limited, 1997; 1998)

Country	Gold Production [tonnes] (1997)	Ranking (1997)	Gold Production [tonnes] (1996)	Ranking (1996)
South Africa	489.2	1	494.6	1
United States	351.4	2	329.3	2
Australia	311.4	3	289.5	3
Canada	168.5	4	163.9	4
China	156.8	5	144.6	5
Russia	137.0	6	132.8	6
Indonesia	101.4	7	92.1	7
Uzbekistan	81.7	8	78.3	8
Peru	74.8	9	64.8	9
Brazil	59.1	10	64.2	10
Ghana *	**55.7**	**11**	**50.3**	**13**
Chile	52.9	12	56.4	11
Papua New Guinea	49.9	13	54.1	12
Philippines	33.8	14	31.8	14
Mexico	26.1	15	24.5	16
Zimbabwe	24.3	16	26.7	15
Venezuela	21.0	17	19.9	18
Colombia	20.6	18	23.1	17
Kyrgyzstan	17.4	19	4.1	37
Mali	16.7	20	6.6	29
Total Gold Production	**2249.7 tonnes**		**2151.6 tonnes**	

* *Country of interest in this study*

Table 1.2: Gold Production by Top Gold Producing Companies in the World – 1996 & 1997

(Gold Fields Mineral Services Limited, 1997; 1998)

Mining Company / Country	**Gold Production [tonnes] (1997)**	**Ranking (1997)**	**Gold Production [tonnes] (1996)**	**Ranking (1996)**
Anglo American Company Limited (now 'Anglogold') [*South Africa*]	226	1	226	1
Newmont Mining Corporation [*United States*]	123	2	97	4
Gold Fields (South Africa) Limited [*South Africa*]	97	3	94	3
Barrick Gold Corporation [*Canada*]	95	4	98	2
Placer Dome [*Canada*]	80	5	60	6
Rio Tinto Plc. [*United Kingdom*]	67	6	60	5
Homestake Mine [*United States*]	57	7	54	7
Freeport McMoRan Copper & Gold Inc. [*United States*]	56	8	53	9
Gencor Limited [*South Africa*]	49	9	53	8
Johannesburg Consolidated Investments [*South Africa*]	45	10	47	11
Normandy Mining Limited [*Australia*]	44	11	45	12
Ashanti Goldfields Company Limited [*Ghana*] *	**36**	**12**	**32**	**14**
Avgold Limited [*South Africa*]	29	13	19	13
Total Gold Production	**1004 tonnes**		**938 tonnes**	

**Mining Company of interest in this study* acid (Kuyucak, 2000; Voella *et al*, 1998; Nicholson, 1994). AMD usually leads to the release of heavy metals, which may move through the biogeochemical cycles until they end in natural sinks such as sediment, soil and biota (Sanchez *et al.*, 1998). These heavy metals can adversely affect soil productivity, plant growth and the food chain (Herbert Jr., 1996). Several cases of surface gold mining-related environmental pollution have been reported, including arsenic and mercury pollution and their adverse impacts on fish, humans and vegetal cover (e.g. Wayne *et al*, 1996; Malm *et al.*, 1996; Barbosa *et al*, 1997; Suchanek *et al.*, 1998; Korte & Coulston, 1998).

Although surface gold mining by its very nature creates risks, environmental risks can be reduced to acceptable limits through appropriate control and mitigation measures – including the use of proven techniques / technologies – at various phases of the mining process (Cragg *et al.*, 1995). For instance, the use of diversion systems, drainage ditches, containment ponds and recycling systems can help minimise water pollution. Again, treatment of air pollutants and the use of dust elimination and suppression techniques helps minimise air pollution associated with surface mining operations (Broman, 1990). Various approaches for minimising the adverse environmental and social impacts of gold mining are discussed in detail in the next chapter (Chapter 2).

In the sections below, gold mining activities in Ghana dating back to the time when it started, are briefly described. Adverse impacts created through mining operations, and measures embarked upon to minimise them, during the 'era of large scale gold mining operations', are particularly emphasised.

1.1 Gold Mining in Ghana: From Past to Present

Gold mining activities have been undertaken in Ghana for several centuries. While diamond, bauxite and manganese were first discovered and mined in Ghana in the 20th Century, gold, on the other hand, has been mined and exported for centuries, with artisanal mining of gold by local populations dating back several years before 1471 (Anin, 1987). Large scale mining of gold, however, did not begin until the 1890's (Anin, 1987; Addy, 1998). Gold mining activities in Ghana from 'pre-European' time to date, are briefly described below:

1.1.1 *Pre-European Era*

Gold was mined in Ghana long before the Europeans arrived in the country (Dickson & Benneh, 1988). The earliest historical records on the Gold Coast (now Ghana) contain unambiguous references to the activities of the Moors (from north-western Africa) and Phoenicians (from the middle-east region) who traded in gold dust and nuggets with the inhabitants of the coast of what is now known as Ghana (Anin, 1987). This was the era of the 'Silent Trade' when the Moors exchanged salt, iron, pewter basins, brass, pots and pans, knives and daggers for gold, ivory, pepper and slaves (Anin, 1987). In addition to its importance in trade, traditionally, gold played a vital role among the Akans, especially in royal circles. In the Ashanti Kingdom which had (and still has) the largest known deposits of ore bodies in Ghana, gold performed the textbook functions of both units and measures of wealth. The Ashanti word for gold is 'Sika' and a wealthy man was called 'Sikani'. Gold was the symbol of wealth and power. It was also the symbol of Ashanti political sovereignty: the famous golden stool was known as 'Sikadwa' (Anin, 1987). Gold was also fabricated into elaborate ornaments by Ashantis and other tribes of the forest belt. The breastplates, anklets and sword hilts of Ashanti Kings were all made of solid gold, demonstrating their wealth (Anin, 1987). Most of the gold supplies during this period were extracted from easily worked alluvial material deposited on river terraces (Dickson & Benneh, 1988). The gold was obtained by washing the sands from the beds or banks of rivers such as the Ankobra and the Birim, flowing over gold-bearing rocks (Boateng, 1959).

Apart from alluvial washing by the side of streams and rivers, Ghanaians also employed pitting, mostly on river flats and terraces and also on the crests of reefs and on detritus. The usual local mining was by means of closely spaced circular pits 0.6 – 0.8m in diameter and in places as much as 50m deep, dug with hoes. Except in very favourable places, adits, tunnels and drives were not constructed and the circular pits were rarely connected at the bottom. The handle of the digging hoe was also used to support the miner when descending (Kesse, 1985).

1.1.2 *European Era*

The Portuguese (specifically, Portuguese merchants) were the European pioneers in the Gold Coast (Kesse, 1985). Arriving in 1471, these merchants, led by Juan de Santerem and Pedro d'Escober, began trading in gold, starting in the south of the country at a village, which they later named *El Mina* (meaning, 'the mine') and is now called Elmina (Kesse 1985; Anin, 1987). Ghanaians exchanged gold for salt, iron, pots / pans, knives and daggers. The search for river basin gold by local people increased as a result of the trade in gold, and intensified around the middle of the 16th Century when some English explorers arrived in the country in search of gold (Anin, 1987). In 1553, two Englishmen, Captain Thomas Wyndham and Antonio Anes Pinteado, traded east and west of Elmina and continued on to as far as River Benin. Captain Wyndham later left the Gold Coast for England with 150 pounds of gold dust worth about £10,000 (Kesse, 1985). A year later (in 1554), another English merchant, John Lock, undertook a similar voyage to the Gold Coast and returned home with a much larger shipment of 400 pounds weight of gold dust (Anin, 1987). In 1555, the English were invited by the chief of Kromantin to build a fort at Kromantin (Kesse, 1987). By the end of the 16th Century, a regular trade in gold dust and nuggets had developed and large amounts were being shipped to England. In all these years, nearly all the gold was obtained from stream and beach gravel by native Ghanaians, using basins and calabashes for washing and concentrating the gold dust. Quoting from one of the early explorers, Anin (1987) gives the following description of the gold mining method used by native Ghanaians during the period: 'They plunged and dived under the most rapid streams with a brass or wooden bowl on their heads, into which they gathered all that they could reach at the bottom.'

The first attempts at hard rock mining in the Gold Coast began in 1482 when Fernando Gomez, a Portuguese, opened up and worked a gold mine at Abrobi Hill, located a few kilometres to the north of Komenda. In 1622, a disaster occurred at this mine, which was then being worked by the King of Guafo. The workings of the mine collapsed, burying all the underground workers. In 1623, the Portuguese discovered a rich gold-bearing reef at Aboasi, 24 km inland from Axim and 8 km up the Duma Creek from its junction with the Ankobra River. Mining operations of this reef were started in 1630 and even a fort was built by the Portuguese to protect their interests. However, on 18th December 1636, the mine collapsed during an earthquake and all the underground miners were killed (Kesse, 1985). Lots of evidence is available of early mining ventures in Ghana but most of the foreigners who obtained mining concessions eventually stopped mining and began to trade in gold. The Africans were left to produce the gold in their own simple way, mining without machinery, water pumps nor compressors and exchanging the hard won gold for cheap goods (Kesse, 1985).

By 1700, and in spite of the fact that no attempt had been made to improve upon the crude methods employed by the people to obtain gold, a very large quantity of the metal was annually exported from the coast, though only a small proportion of the metal passed through the hands of the legitimate companies. It is reckoned that the annual trade in gold was about £200,000 (Kesse, 1985). The trade in gold between Ghanaians and the Europeans (who, at this time included the Dutch, the Danes and the French) was by barter and took place mostly on the seashore where neither the buyer nor the seller met each other (Kesse, 1985).

1.1.3 *Mining of Gold-Bearing Rock / Modern Mining*

Surface / underground gold mining began at an appreciable scale in the Gold Coast in the early parts of the 19^{th} Century, and took the following form described by an explorer and reported by Anin (1987):

- The shafts were 80 feet (24 m) or less in depth, 2 feet (0.6 m) in diameter and not timbered
- They were dug with a hoe, and the loosened soil was handed up in calabashes
- In the search for lode gold, the natives dug as if forming a well until they came to a dark coloured stone which is interspersed with gold
- With the aid of imported hammers, the diggers broke and recovered the ore which they carried to their homes and ground to a fine powder on a slab of granite
- The powdered ore was then collected in calabashes and washed by the women-folk
- With no water pumps, workings were restricted to areas above the water table and most digging was carried out in the dry season

The gold mining / processing method above continued until the 1870's when modern equipment came into use (Anin, 1987). Modern mining in the Gold Coast, involving the use of machinery and the working of both alluvial deposits and ores began in about 1880 in the Tarkwa area. A Frenchman, Monsieur Pierre Bonnet who had been prospecting in the area, first reported the possibilities of mining gold in the area in 1877. He later formed a mining company – the African Gold Coast Company – and obtained a concession at Tarkwa. This was known as Bonnet's concession. Bonnet is therefore known as 'The Father of Gold Mining' in Ghana (Kesse, 1985). He also opened mines at Abosso, Tamsoo and Efuanta. In the same year, Dr. A Hortson, after whom several of the Tarkwa concessions were named, obtained concessions at Abontiakrom, Tamsoo and a place near Dixcove (Kesse, 1985). Other companies soon followed when the richness of the ore in this area became known. By the end of 1883, many gold mining companies (including Swanzy and Company, the Efuanta Gold Mining Company and the Gold Coast Mining Company) had obtained concessions in the Tarkwa area (Kesse, 1985). By the 1890's, there was mining everywhere in the Tarkwa Hills (Dickson & Benneh, 1988). Between 1892 and 1901, there was a large wave of speculation and prospecting for gold in Ghana and this became known as the 'Jungle Boom'. During that time, about 400 companies, with a total nominal capital of some £40 million, were formed to work concessions in many parts of the country. However, only few of them survived (Kesse, 1985) due to the high cost of transport to and from the coast, and the irregular supply of labour, among others (Dickson & Benneh, 1988). It was during this period that the Ashanti Goldfields Corporation (AGC) Limited was formed, following the developments below (Kesse, 1985):

- In 1890, three Ghanaian (Fanti) Concessionaires, Joseph Ettruson Ellis, Joseph Edmund Biney and Joseph Peter Brown, obtained a lease in the Obuasi area from the King of Bekwai
- A shaft was sunk and a small hand-powered three-stamp mill with amalgamation plates was used to crush the quartz ore
- In 1895, rock specimens from these workings sent by a Cape Coast business associate reached the office of Mr. Edwin Arthur Cade, a West African merchant

in the city of London – the specimens were rich enough to warrant further investigation

- Cade raised some capital and formed the Cote d'Or Mining Company. He visited the site of the mine and bought the concession of 258 square kilometres from Mr. J.E. Biney and colleages
- Mr. Cade returned to London and on 3rd June 1897, and in association with some rich friends, formed the now-famous Ashanti Goldfields Company (Ghana) Limited, to take over the interests of the Cote d'Or company
- A lease was granted to AGC Limited for 90 years, effective from 1st January, 1897

Large scale gold production in Ghana began not long after a team, which comprised miners, fitters and assayers, arrived at Obuasi from London, and commenced underground gold mining operations in AGC's Obuasi concession using sophisticated equipment (Anin, 1987). After 1914, the newly formed Geological Survey Department discovered more gold deposits in several areas in the forest region of Ghana, and at Nangodi in Northern Ghana. These were worked by mining companies, but for limited periods in some cases. The Nangodi mine, for example, was closed down towards the end of the Second World War (Dickson & Benneh, 1988).

The Second World War (1939 – 1945) caused stagnation in gold mining, followed by a near collapse of the gold mining industry in the Gold Coast. Many mines were closed and many exploration ventures were postponed (Kesse, 1985). After the war, the general political awareness in the country, culminating in Ghana's national independence in 1957, did not encourage the opening of new mines by foreign companies (Kesse, 1985).

Available estimated figures on gold production levels in Ghana before 1900 are as follows (Mireku-Gyima & Suglo, 1993):

- From 1493 to 1600 – 254 tonnes, representing 35.5% of the entire world's gold during that period
- 1601 to 1700 – 200 tonnes, representing 23% of total world gold production during the period
- 1701 to 1800 – 170 tonnes

Between 1880 and 1900, 363,480 ounces of fine gold estimated at £80 million was produced in the Gold Coast (Ghana Chamber of Mines, 1997). This is worth an estimated £562 million per annum (at today's price of $ 354.75 per ounce of fine gold). The Ghana Chamber of Mines [GCM] (2000) has compiled data on gold production in Ghana since 1900. Figure 1.1 (derived from GCM's data set) presents the annual gold production in Ghana in every 10th year between 1900 and 1990, and annual gold production from 1991 to 1999. Between 1997 and 1999, gold production by 7 top gold-producing companies in Ghana are shown in Table 1.3. It can be seen from Figure 1.1 and Table 1.3 that gold production in Ghana increased steadily between 1900 and 1990, and rapidly after 1990 (see Figure 1. 1). From studies on current gold deposits in Ghana, it is envisaged that gold exploitation in the country will continue for several decades (Addy, 1998).

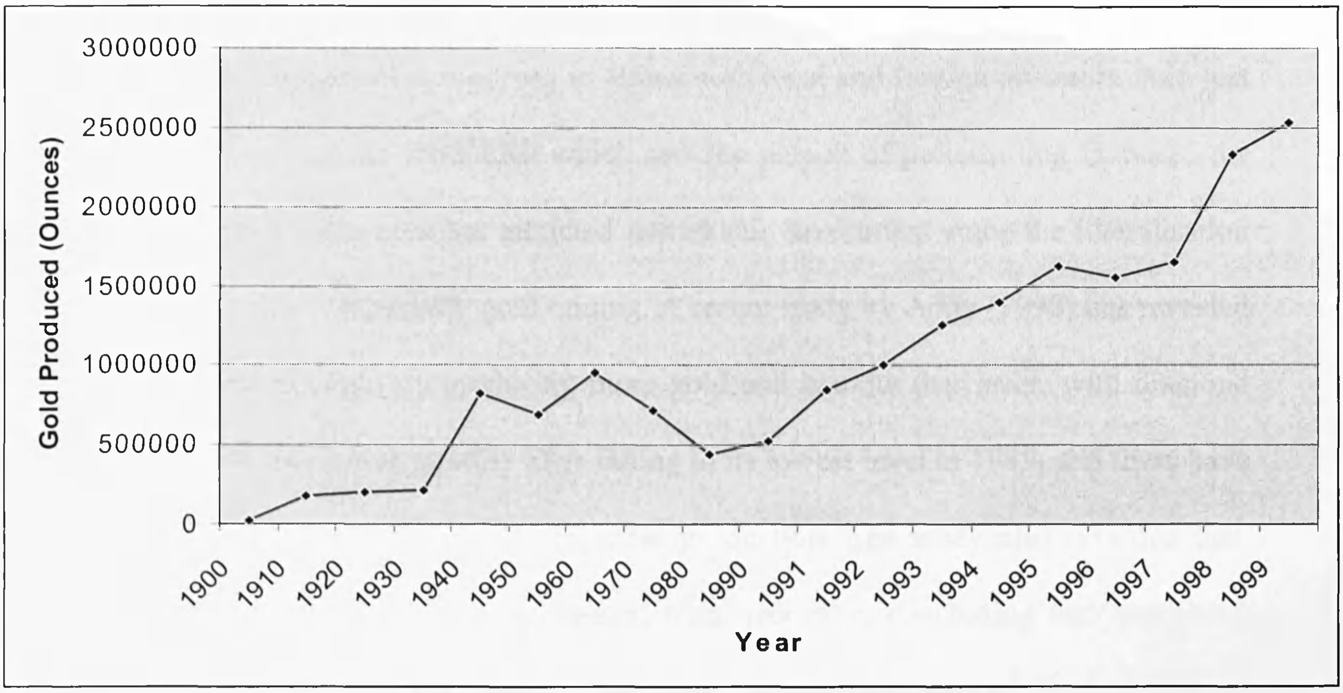

Figure 1.1: Graph showing Annual Gold Production in Ghana from 1900 to 1999 (Derived from Ghana Chamber of Mines, 2000)

1.1.4 ***The Current Situation***

Since 1983 when the government of Ghana embarked upon an Economic Recovery Programme (ERP) to resuscitate the hitherto receding economy, a number of policies aimed at creating a favourable climate for investment, especially, in Agriculture and Industry, have been pursued. In the mining sector, these policies including tax rate reductions, removal of restrictions regarding transfer of dividends and divestiture of state interests (Addy, 1998) led to active rehabilitation of old mines and the establishment of many new ones, both large and small scale, a few years after implementation of these policies. Then again, in January 1995 the government outlined a programme, coded 'Vision 2020' focusing on steps that would be taken to transform Ghana into a 'middle income' country by the year 2020, with the private sector as the engine of growth for the economy. Strategies adopted for the realisation of this 'vision' have included the establishment of an open and liberal market economy to attract both local and foreign investors. And just as in the case of the 1983 ERP which saw the pursuit of policies that favoured the mining sector, this area has attracted remarkable investment since the liberalisation of the economy, especially gold mining. A recent study by Addy (1998) has revealed that Ghana is currently producing more gold and bauxite than ever, with diamond production increasing steadily after falling to its lowest level in 1989, and there have been significant increases in manganese production. The study also revealed that, following the building of a successful track record in concluding and honouring mining agreements, the country has been attracting a lot of foreign mining investment over the years. In fact, as at the end of 1998, there were over twenty-five mining companies engaged in active mining, with more than sixty-seven other companies granted prospecting / reconnaissance licences (Ghana Chamber Of Mines, 1999).

The positive impacts accruing from mining activities in Ghana cannot be overemphasised. The mining industry employs more than 7% of the labour force in the country (Al-Hassan *et al.*, 1997). The country derives a significant proportion of her export earnings [(46% in 1998 – (Ghana Chamber of Mines, 1999)] from mineral resources, with gold contributing approximately 90% of the total, whilst diamond, bauxite and manganese provide the rest (Ghana Chamber of Mines, 1999; Al-Hassan *et al.*, 1997). Generally, the Central Government of Ghana, and hence, the nation as a whole benefits greatly from mining operations through dividends, foreign exchange earnings and royalties paid by mining companies in accordance with statutory requirements enshrined in the Minerals and Mining Law, 1986 [Government of Ghana Law 153] (Government of Ghana, 1986). These provisions

Table 1.3: Annual Production of Gold (1997 to 1999) by Seven Top Gold-Producing Companies in Ghana (Derived from Ghana Chamber of Mines, 1998; 1999; 2000)

Mining Company	Gold Production (Ounces)	Value ($) **
1997		
Ashanti Goldfields Company (AGC) Limited *	1,039,449	341,604,413
Teberebie Goldfields Limited	238,804	81,263,175
Bogoso Gold Limited *	108,388	38,599,097
Gold Fields (Ghana) Limited	53,771	16,360,485
Resolute Amansie Limited *	39,903	16,118,932
Bonte Gold Mines Limited *	34,839	11,253,225
Banex (Prestea) Limited	33,483	10,011,551
Total Gold Production (Ounces) / Value ($)	**1,548,637 Ounces**	**$515,210,878**
1998		
Ashanti Goldfields Company (AGC) Limited *	1,233,820	363,251,076
Abosso Goldfields Limited	270,735	79,493,328
Teberebie Goldfields Limited	253,238	74,180,055
Resolute Amansie Limited *	173,975	51,073,332
Gold Fields (Ghana) Limited	135,769	36,522,385
Bogoso Gold Limited *	122,587	35,092,139
Bonte Gold Mines Limited *	35,135	10,341,467
Total Gold Production (Ounces) / Value ($)	**2,225,259 Ounces**	**$649,953,782**
1999		
Ashanti Goldfields Company (AGC) Limited *	1,213,134	340,203,019
Abosso Goldfields Limited	303,693	88,070,970
Teberebie Goldfields Limited	275,634	73,412,591
Gold Fields (Ghana) Limited	255,793	54,330,843
Resolute Amansie Limited *	136,000	38,080,000
Bogoso Gold Limited *	130,463	36,877,925
Satellites Goldfields Limited	87,192	26,400,000
Total Gold Production (Ounces) / Value ($)	**2,401,909 Ounces**	**$657,375,348**

* *Mining Companies of interest in this study* ; ** *Estimated value of gold sold as at the end of stated year*

include a 10% mandatory interest in the rights and obligations of mineral operations without any financial contribution by the government [Section 8 (1)] and an option by the government to acquire a further 20% stake in mining operations where the mineral concerned is in commercial quantities [Section 8 (2)]. Under Sections 22 (1) and (2) of the law, mining companies are obliged to pay royalties to the state government [Section 22 (1)], Traditional Councils and District Assemblies [Section 22 (2)]. While 3 – 12 % of a mining company's gross revenue (based on profitability of the mine) is paid as royalties to the State Government / District Assembly (in the mining area in question), a percentage of the total amount (usually 1%) is made available to the traditional council in the mining area, for community development. Again, a holder of a mining lease is required by the law to pay income tax at the rate of forty-five percent (45%) [Section 23 (1)] and Additional Profit Tax [Section 23 (2)] as provided under the Additional Profit Tax Law, 1995 [Government of Ghana Law 122] (Government of Ghana, 1995). In addition to the direct taxes and royalties described above, more revenue accrues to the nation (indirectly from the mining industry) from the taxes paid by businesses that the mining companies have given birth to or helped to grow. These businesses include transport companies and international companies servicing the numerous mining companies (Al-Hassan *et al.*, 1997). The rapid growth of the mining industry has encouraged the migration of people seeking jobs to mining centres, and this has helped to retain people in rural areas. This has had the effect of minimising the rural-urban drift, and has succeeded in reversing it to urban-rural drift, to the extent that some villages in the mining areas are already 'congested' (Al-Hassan *et al.*, 1997). The provision of jobs for the rural folk has raised their standard of living as a result of increased income (Al-Hassan *et al.*, 1997). However, despite all the positive mining impacts enumerated above, over the years mineral production activities in Ghana have been beset with a number of negative environmental and socio-economic impacts, which are outlined below.

The negative mining impacts documented for Ghana range from land degradation, landuse conflicts, loss of water quality / total destruction of water sources, air pollution (especially dust), noise and ground vibration to total relocation of communities from one locality to the other (Al-Hassan *et al.*, 1997). Many water bodies (in some cases, the only sources of potable water available to rural communities) have been rendered unsuitable for drinking due to pollution from mining operations. A visit to many of the well-established mining companies in the country reveals a myriad of environmental problems such as gullying, soil compaction, erosion, waterlogging and lack of, and / or defoliation of, vegetal cover. In addition to the above impacts, the mining-induced vibrant economy and the competition for food and other basic commodities has drastically increased the cost of living in the mining areas. In some cases, it has affected education as children abandon school in search of menial jobs at the mines. Parental control over their children has also broken down in many rural areas close to mines, as the children secure jobs at the mines and fend for themselves (Al-Hassan *et al.*, 1997). Population increase in the mining areas has also brought with it health hazards, increasing crime waves, sexual promiscuity with its attendant spread of communicable diseases such as syphilis, gonorrhoea and the Acquired Immune Deficiency Syndrome (AIDS), as well as cultural adulteration (Al-Hassan *et al.*, 1997).

Although this study focuses on the environmental impacts of large-scale gold mining activities in southern Ghana, it must be stated that small-scale mining operations in the country contribute to most of the negative mining impacts outlined above. Intensive small-scale mining activities (locally called *galamsey*) – involving both legal and illegal operations – are undertaken along the northeast-southwest gold belt of Ghana (Aryee *et al.*, 2003). Legal workings operate under a license granted by the Minerals Commission of Ghana on concessions registered in the names of individuals or small groups who, in a majority of cases, are well organised and have access to extension services. Illegal operators, on the other hand, operate without a license, have no concessions of their own and operate uncontrollably within the concessions of large-scale mining companies or in areas prohibited for mining such as forest reserves. Most small-scale mining activities in Ghana involve the mining of alluvial ores, and only in a few cases, hard rock ores. Uncontrolled alluvial mining commonly damages stream banks and channel morphology. The processing of alluvial ores involves the sluicing of mined materials in a sluice box to obtain concentrate. Mercury is then added to the concentrate and mixed to form a gold amalgam, which is then heated to separate the gold. In the case of hard rock ores, traditional or manual methods featuring artisanal implements are typically used. This involves 'pounding' (crushing and grinding) using locally designed metal mortars and pestles. The resultant powder is then sluiced to obtain a gold concentrate, which is later amalgamated with mercury and heated to separate the gold (Aryee *et al.*, 2003). Environmental problems such as deforestation, land degradation and water pollution resulting from small-scale gold mining activities in Ghana (including southern Ghana) have been reported by many researchers (e.g. Hilson, 2002a; Aryee *et al.*, 2003; Babut *et al.*, 2003). Aryee *et al* (2003) for instance, have identified degraded landscapes consisting of unstable piles of waste, abandoned excavations and vast stretches of barren land resulting from small-scale gold mining operations in many mining areas in Ghana. The drainage system in many small-scale mining areas in the country is adversely affected by mining operations. Rivers and streams are polluted by solid suspensions and mercury, which are commonly discharged into water bodies during the sluicing and amalgamation processes, causing water pollution problems (Babut *et al.*, 2003). Improperly disposed tailings also find their way into rivers and streams during heavy rains, creating sedimentation problems and rendering streams unusable for both domestic and industrial purposes (Aryee *et al.*, 2003).

Studying the impacts of small-scale mining activities in Ghana can be a rather difficult task, due to the proliferation of illegal mining operations in the country. In fact, this study does not attempt to delve into environmental and other issues in the Ghanaian small-scale mining sector. It is a subject area that requires more attention. The remaining sections of this chapter focus on large-scale mining operations in Ghana.

In its 1996 Annual Report, the Environmental Protection Agency of Ghana (1997) made the comments below in respect of the mining sector, following a monitoring programme at some of the major mines in the country in 1996:

- Dust control measures at most of the mines are largely ineffective particularly, in the Harmattan season
- There exist water pollution problems at some mines
- Resettled communities lack sufficient potable water during the Harmattan season

- Rate and quality of reclamation of disturbed areas are not satisfactory at some of the mines
- There is a generally low level of implementation of Environmental Action Plans by companies
- Company-community relations are poor at some mines

With the enactment and promulgation of the Environmental Protection Agency Act 1994 [Government of Ghana Act 490] (Government of Ghana, 1994), all undertakings with major environmental impacts, including 'large scale' mining are to be registered with the Environmental Protection Agency. After an initial assessment of the potential impacts of the project, if the EPA finds the adverse impacts to be significant, proponents are made to submit Environmental Impact Statements on their undertaking. This notwithstanding, most Environmental Impact Statements presented by mining companies have concentrated on measures to be put in place to minimise impacts. Meanwhile, a lot of harm (both social and environmental) has already been done through unchecked operations of the past. These problems include pollution of soils and water bodies with heavy metals and residues of ore processing chemicals in some of the mining areas (e.g., Amasa, 1975; Amonoo-Neizer and Amekor, 1993; Amonoo-Neizer *et al.*, 1996). Again, a visit to most of the active mining areas in the country reveals that environmental management programmes pursued at the mines leave a lot to be desired. From a careful analysis of the adverse impacts of mining in Ghana on the one hand, and, the environmental management programmes pursued at most of the mines on the other, it can be hypothesised that most of the negative impacts associated with mining in Ghana have their roots in the types of environmental management practice operated at the mines. It can also be hypothesised that most of the environmental and socio-economic problems associated with mining activities in Ghana can be prevented, or at least, reduced to barest minimum levels through the use of:

- Exploration, mining and ore processing techniques that are based on the design / plans which incorporate good environmental management practice in the mining process (including the application of appropriate environmental management techniques at every stage of the mining cycle)
- A well-coordinated approach to environmental management that incorporates environmental management tools including an effective EIA process, environmental planning, management, monitoring and auditing programmes

The above approaches to environmental management call for the establishment of a corporate Environmental Management System (EMS) that sets out policies, principles and guidelines (Brooks *et al.*, 1996). Among other things, a competently implemented EMS, according to Environment Australia (1995g), should:

- assist compliance with regulatory requirements
- assist a company to meet its own targets
- improve customer and investor satisfaction
- improve a company's public image
- improve relations with the local community
- improve relations with regulatory authorities
- make licences and permits easier to obtain
- improve future access to sites

- reduce environmental impacts
- demonstrate due diligence
- improve access to capital
- decrease a company's liabilities
- improve company relations with employees
- allow greater control of operations and costs

It must be stated that, although there have been studies on the impacts of mining on the environment and rural communities in mining areas in Ghana, most of these studies (e.g., Amasa, 1975; Amonoo-Neizer and Amekor, 1993; Amonoo-Neizer *et al.*, 1996), have in the main, focused on identification and / or quantification of the impacts rather than tackling them. For instance, no study has been undertaken to examine the types, viability and effectiveness of environmental management measures applied by the mining companies in the country, to minimise environmental and socio-economic impacts created by their activities. Neither has there been a study that examines how mining area communities in Ghana perceive the environmental and socio-economic impacts of mining in their localities. This study, the focus of which is outlined below, seeks to provide this knowledge, which is crucial to the design of effective environmental management programmes to minimise the adverse impacts of gold mining in Ghana.

1.2 Scope of Research

This study is aimed at developing a framework / structure for the development of an appropriate EMS to help mitigate the negative impacts of surface gold mining in southern Ghana and has the following specific objectives:

- To examine environmental impacts of surface gold mining in southern Ghana and their direct and indirect impacts on humans, aquatic and terrestrial flora and fauna, and their habitats (biotic and abiotic components of the environment)
- To measure / assess current environmental management practices / techniques employed by the mining companies in southern Ghana against Best Practice Environmental Management (BPEM) in mining
- To assess the effectiveness of environmental management programmes of mining companies in southern Ghana, in the mitigation of the negative impacts associated with their mining operations
- To propose new approaches to managing mining impact problems in southern Ghana within the context of the peculiar climatic, geological, hydrological, topographic, soil, social and other conditions that characterise the mining areas in the region

It must be stressed that the emphasis of this research is on the assessment of the effectiveness of current *environmental management* programmes being pursued by *large-scale* gold mining companies in southern Ghana. The study then explores ways by which environmental management can be improved to promote environmentally and socially responsible mining in the region. Thus, although from time to time (especially in Chapters 5 and 7 of the thesis) some reference is made to results of scientific investigations – mainly monitoring data collected by mining companies in the study area – issues regarding environmental management, planning and policy are the fulcrum around which the current study evolves. No formal scientific investigations were undertaken with respect to the measurement or monitoring of environmental parameters as part of this study. Consequently, proposals and recommendations made (Chapter 7) and the conclusions drawn (Chapter 8) in this thesis hinge on the principles of environmental management rather than environmental science. In writing this account, I have also drawn on experience gained as a Senior Programme Officer with the Environmental Protection Agency of Ghana.

1.3 **Structure of Thesis**

The thesis consists of eight chapters. Chapter One briefly outlines the history of gold mining in Ghana, impacts created through mining operations and how these impacts are being mitigated. The chapter also provides an overview of gold production trends in Ghana over the years, provides a background to the current study, and spells out the main aim and objectives of the study. In Chapter Two, available literature on gold mining processes and the impacts associated with the various phases of mining, as well as literature on various approaches employed in the minimisation of adverse mining impacts, is explored. This is to help gain some understanding of gold mining processes, impacts and adverse impact management, from a global perspective. Chapter Three describes the methods used for the collection of field data for the research (data from selected mining companies and mining area communities in southern Ghana and, from selected government and research institutions). An understanding of the geo-environmental characteristics of a mining area and its surroundings is necessary for the design of appropriate environmental management programmes to minimise adverse mining impacts (Down and Stocks, 1977). In Chapter Four, the geo-environmental characteristics of four mining areas selected for this study are outlined. The data collected from the four mining companies in the study area and sixteen communities in the region are presented in Chapters Five and Six respectively. These data are discussed in Chapter Seven. In this chapter also, recommendations which may be of help to mining companies in southern Ghana in their bid to embark upon environmentally and socially responsible mining, are presented. Conclusions emanating from the results and discussions are presented in the last chapter of the thesis – Chapter Eight.

CHAPTER TWO

SURFACE GOLD MINING PROCESSES, IMPACTS AND ADVERSE IMPACT MANAGEMENT: A LITERATURE SURVEY

2.1 **Introduction**

All mining activity leads to some form of impact on the environment (Down & Stocks, 1977; Kent, 1986; Salomons, 1995; Ripley *et al.*, 1996). Mining operations generate a wide range of environmental impacts resulting from the extraction, processing, storage and transportation of minerals and mineral products (Richards & Armstrong, 1996). Mineral extraction and processing activities can be extremely environmentally destructive and over the course of many years, can cause irreversible damage to surrounding landscapes. Of these, a great number are unavoidable, and can only be remedied at the time of decommissioning (Hilson, 2002b). In the course of mining, large tracts of forest may be removed to gain access to underlying ore bodies, for the construction of staff housing and establishment of processing plants. In the process, a vast quantity of often-productive topsoil, through continuous exposure to surface erosion under intense tropical rainfall, may erode and collect in nearby water bodies (Hilson, 2002b). The mining of minerals often results in environmental impacts far beyond the area mined. This is because the mining process can liberate mobile contaminants, which can be carried considerable distances from the mine site (Farrell & Kratzing, 1996). The extent of the mining impact can range from scarcely perceptible to highly destructive and the nature of the impact can similarly vary widely depending on the mineral worked, the method of mining and the characteristics of the mine site and its surroundings (Down & Stocks, 1977). In particular, the type of mining method used has a major influence upon both the nature and extent of the environmental impact caused. For instance, surface mining, despite its many economic advantages (including low costs, high productivity, low capital investment and short development time), has a much larger environmental 'footprint' than normal underground operations (Cragg *et al.*, 1995). Generally, surface mining is cheaper than underground mining and thus permits the working of lower grade ore bodies, thereby increasing economically available reserves of the mineral being extracted. Again, a higher percentage recovery of valuable mineral is achieved as compared with underground extraction techniques, thus improving overall resource utilisation (Down & Stocks, 1977). However, many environmental impacts are at a maximum in surface mining operations (Down & Stocks, 1977). Apart from the issue of taking several hectares of land out of other uses such as farming, forestry and recreation, surface mining has associated with it nuisance effects caused by noise, dust and traffic, visual intrusion, air blast, ground vibration, air and water pollution and dereliction (Down & Stocks, 1977; Richards & Armstrong, 1996).

The various adverse impacts associated with surface mining are linked to the operations involved in mining activities (Richards & Armstrong, 1996). Thus environmental impacts of mining activities can be most effectively characterised by consideration of the different operations involved such as extraction, processing, waste disposal, transport and site management (Richards & Armstrong, 1996). Within each of these major operations, a number of different processes can be identified. For example, the extraction process incorporates soil stripping and storage, on-site transport, overburden removal and storage, backfilling and dewatering, with each process having its own environmental repercussions (Richards & Armstrong, 1996). The exact nature of these environmental effects depends on a wide variation of circumstances in each case, reflecting different geological conditions, site settings and operational characteristics. There are, therefore, wide variations not only between operations involving different minerals, but also between different sites where similar minerals are extracted (Richards & Armstrong, 1996). Edaphic, economic and social factors that prevail in the mining area also greatly influence the nature and the extent of mining impacts (Down & Stocks, 1977). Various authors (for example, Kellman & Tackaberry, 1997; Young, 1976; Jackson, 1989 and Reading *et al.*, 1995) have identified the following peculiar characteristics of humid tropical environments that have implications for planning and the types of technique required to reduce environmental impacts of mining in such areas:

- Rainfall is mostly convective and of high intensity
- Approximately 40 per cent of the rainstorms exceed 25 mm h^{-1}, a rate considered to be the threshold intensity at which rainfall becomes erosive
- Thunderstorms are often accompanied by severe downbursts of wind which combine with the heavy rainfall to cause severe wind erosion and flooding problems
- The seasonality of rainfall exerts an overall control on water availability while the intensity, duration and frequency of individual rainfall events affect the pattern of hydrological routeways through river / stream catchments. A key point

is that in the tropics, a high proportion of rainfall occurs during high magnitude, high intensity storms and is usually characterised by flooding

- Due to the large volume of water that percolates through the soils which have low cation exchange capacity, leaching of chemicals is high

In order to assess and remedy environmental disruption attributable to mining, a logical sequence would be to (Down & Stocks, 1977):

- Express the nature and extent of the impact with reference to a rational and consistent system of measurement
- Define acceptable standards and criteria in a comparable manner
- Compare the measured (or predicted) impact with the relevant standards
- Implement remedial measures, if necessary, to reduce the impact to conform to the accepted standards

However, according to the above authors, there are relatively few occasions on which it is practicable to follow the idealised sequence above due to the following difficulties:

- For many types of environmental problems, there are no consistent and accepted techniques available to quantify the extent of the impact. This is particularly the case when loss of amenity occurs, in which case assessment is frequently qualitative rather than quantitative and thus contains a strong element of subjectivity

- Well-defined and generally accepted criteria exist for only a minority of environmental problems. Some types of impact, such as visual intrusion seem inherently unsuited to measurement and standardisation since they are inevitably concerned with subjective reaction
- There may be no known remedy capable of reducing a particular problem to generally acceptable levels

The list above would have been more conclusive if it included 'lack of baseline studies'. Lack of baseline studies is a major factor that makes the design and implementation of 'appropriate' environment management programmes a rather difficult task for mine environmental managers. This problem is more pronounced in developing countries. Reading *et al* (1995), for instance, have bemoaned the inadequacy of knowledge of the humid tropical weather systems in West Africa, as a result of dearth of synoptic stations (particularly over the long term), to record data for monitoring and other purposes. Baseline data are required, to provide information on the environmental systems that exist prior to any disturbance or, the status of an altered system at a particular point in time, prior to additional change (Allan & Southern, 1996). In addition to providing a control whereby project impacts can be predicted, and in the longer term, evaluated, baseline data provide the basis for future monitoring (Allan & Southern, 1996). However, there is a potential problem with the use of baseline data in providing information required to enable facilities to be designed to minimise adverse mining impacts (Allan & Southern, 1996). This stems from the fact that during the very early stages of project evaluation it is likely that the project will be imprecisely defined with regard to decisions on mining methods, support services and production rates yet to be made

(Allan & Southern, 1996). This problem can be partly overcome by structuring the studies in a staged manner. Preliminary surveys can provide initial information to enable following work to have a better focus (Allan & Southern, 1996).

Generally, mining companies face complex problems assessing the environmental effects of their operations for two principal reasons: (i), the wide range and large number of possible environmental effects and (ii), the inherent difficulties in assessing the significance of some of these impacts (Richards & Armstrong, 1996). The above problems, notwithstanding, several methodologies have been applied using approaches ranging from scientific (toxicological), legislative ('effects are only regarded as significant when covered by legislation'), perceptual (based on consultation with communities) to health- and safety-based methodologies for environmental assessment in the mining industry (Richards & Armstrong, 1996). In mining operations, Environmental Impact Assessment (EIA) helps to protect the environment by looking at the likely environmental effects of impacts from all stages of the mining project from exploration and planning, through construction, operations, decommissioning and beyond site closure (Environment Australia, 1995c). Once the key adverse impacts associated with a mining operation have been identified, steps can then be taken to reduce these impacts to acceptable limits (Richards & Armstrong, 1996). This can be achieved through effective planning in all aspects of the mining process, taking into account all environmental protection, cultural, social, economic, religious and land use impacts as well as safety issues identified during the impact assessment process (Cragg *et al.*, 1995). It must be stressed that monitoring and auditing are essential mechanisms for ensuring accountability in the EIA process. However, in many African countries, these activities are hardly carried out due to the following reasons among others: a limited budget for monitoring; the people affected are rarely involved; and a lack of extension staff (Kakonge, 1998). Even when monitoring has been done, information collected is often not analysed or used systematically to help redress conflict and prevent recurrence (Kakonge, 1998). The Environmental Protection Agency of Ghana – the main environmental regulatory body in Ghana – finds it very difficult to monitor mining operations in the country to appropriate technical levels due to inadequate personnel and lack of funds. In 1998 the Agency sponsored twelve staff (one staff from each of the ten Regions, and two from the Head Office – Accra) in a 3-month training programme at the Environment Protection Agency of Victoria, Melbourne. The staff were mainly trained in the analysis of air and water samples for the monitoring of air and water pollution. The purpose of the training was that on their return, they would train / guide other staff in the analysis of air and water samples in laboratories the Agency intended to establish in each Region of the country. Unfortunately however, only one laboratory has so far been established – in Accra (Head Office). A recent study by Domfe (2003) confirms the problem of inadequate staffing at the EPA. This author further comments on how a lack of laboratories in the Regions makes monitoring of mining impacts difficult for EPA. However, Domfe's (2003) comment that EPA (Ghana) finds it difficult to analyse data received from over 200 mining companies in the country is misleading. In fact, the EPA (since 1998) has made it mandatory for all large-scale mining companies in the country to monitor water and air samples in their mining area themselves and submit monthly reports (monitoring results) to the Agency. However, from time to time, the Environmental Quality Department of the Agency takes samples from selected mining areas for analysis in Accra as a matter of routine or following complaints from the general public.

Proven approaches to mitigating the adverse impacts of surface mining include the use of environmentally friendly technologies and techniques at various stages of the mining process (Forey & Grubler, 1996; Warhurst & Bridge, 1996) including technologies that can reduce both environmental and economic costs (Auty & Warhurst, 1993). In fact, growing evidence suggests that improving a mine's environmental management may not be detrimental to economic performance, and in some cases, may even provide considerable economic benefits (Warhurst, 1993). For effective management of environmental impacts of mining operations, the environmental management process in operation at the mine needs to be fully integrated with the other planning and management systems. Again, environmental management needs to be integrated into all phases of the mining company's operations, including exploration, project evaluation and planning, construction, commissioning, operations, decommissioning and lease relinquishment (Brooks *et al.*, 1996). This calls for the establishment of a corporate Environmental Management System (EMS) that sets out policies, principles and guidelines (Brooks *et al.*, 1996) that would enable the company to pursue high environmental standards both for reasons of environmental sustainability and for the benefit of communities affected by mining operations (Richards & Armstrong, 1996).

An EMS is an organisation's formal structure for environmental management and encompasses procedures, practices, processes and resources (Parker *et al.,* 1994). It is a method of: (i), ensuring and demonstrating the organisation's compliance with relevant laws and regulations on an on-going basis, and (ii), demonstrating this compliance to others (Parker *et al.*, 1994). The structure and content of the EMS will be governed by the size and complexity of the organisation, as well as by its management philosophy. For a company with a single operation, the EMS can be relatively straightforward, and can clearly focus on the operational issues facing the site. In contrast, a multi-site organisation needs to construct its EMS to take account of its corporate needs and responsibilities as well as those at the operational level in such a way that a consistent approach is adopted across the group (Brooks *et al.*, 1996). Environmental Management Systems are generally based on total quality management (Parker *et al.*, 1994) and on such standards as BS 7750, EMAS and ISO-14001 developed by the British Standards Institution, the Commission of the European Communities and the International Organisation for Standardisation respectively (Richards & Armstrong, 1996).

In general, the first step towards establishing an environmental management system is the drafting of an environmental policy statement against which the company's performance can be measured. It should contain specific, and where possible, quantified commitments to environmental improvements, rather than generalisations. This should therefore be open to audit and monitoring. Next is required the creation of codes of practice for specific operations or responsibilities including the establishment of goals or targets for further improvement of environmental performance (Ryall and Pinder, 1994). The environmental policy statement should thus spell out the intended steps to be taken towards achieving the following targets among others (Ryall and Pinder, 1994):

- Undertaking EIAs for all new operations
- Minimising all environmental impacts of operations
- Maintaining quality standards
- Taking positive steps towards conserving natural resources

2.2. **Surface Mining Processes and their Associated Impacts**

In one consideration of environmental effects of mining, the mineral mining industry was described as consisting of five stages (Ripley *et al.*, 1979):

- Exploration – the geological, geochemical and geophysical surveying of an area to delimit ore bodies, plus an exploratory stripping or excavation
- Development – the preparation of the mine for production, including the building of access roads and surface facilities
- Extraction – ore removal activities
- Beneficiation – concentration of the ore from low or medium grade deposit; this usually occurs near the mine site and results in the removal of the ore from the gangue
- Processing – may include refinement of the concentrated ore; this is usually carried out at any distance from the mine

The first three stages occur in succession; however, once the mine is operational, extraction, benefeciation and processing will occur at the same time (Kelly, 1988). Thus in their description of the main processes of mining operations, Farrel and Kratzing (1996) categorised mining activities into two main phases – Exploration phase and, Mining and Production phase. One important phase of the mineral development process which the above authors (Ripley *et al.*, 1979; Kratzing, 1996) failed to make reference to – despite the various adverse impacts it can create if not properly executed – is mine decommissioning. Brooks *et al* (1996), for instance, included this phase in the list of processes that they recommended environmental management has to be integrated into for environmentally sustainable mining. Associated with each of the phases of mining are several impacts as outlined below:

2.2.1 ***Exploration***

Exploration for minerals is the first stage of the mineral development process and involves the use of knowledge and technology to search for clues that a commercial prospect might exist (Farrell & Kratzing, 1996; Environment Australia, 1996). Exploration is a progressive technique, initially covering a wide area of land with techniques causing the least impact, and then progressing to a more restricted area as the targets get better defined. Thus the environmental impacts of exploration depend on the particular stage of events (Farrell & Kratzing, 1996).

The initial phase of exploration, often termed reconnaissance survey, is typically undertaken after a permit to explore is granted by government to a company or individual. The techniques involved are generally non-intrusive or remote from the ground surface. Remote sensing surveys such as satellite photography, thermal scanning and multi-spectral radar- or helicopter-mounted low level thermal or magnetic scanning are usually used. Typical impacts in this phase of exploration are thus restricted to any transient disturbance from low-flying aircraft (Farrell &

Kratzing, 1996). While planes or helicopters may disturb animals, there is no evidence available to show that the effects are adverse or long lasting (Farrell & Kratzing, 1996). Reconnaissance exploration will usually identify specific target areas for closer investigation (Environment Australia, 1996), following interpretation of data obtained through the aerial survey (Farrell & Kratzing, 1996). This investigation typically consists of ground surveys by geologists working on foot and collecting samples of surface rock, soil and stream and lake sediments. Subsequent investigations may involve the use of hand-held soil augers to extract sub-surface samples, usually on a grid pattern. This sampling, along with geological and geophysical mapping, is used to locate geochemically anomalous areas for more detailed work (Farrell & Kratzing, 1996). As targets are identified as a result of the preliminary exploration, further intensive exploration is conducted on a lower number of smaller targets. Typically, the size of an exploration tenement is reduced by relinquishing parts of the permit area. If an area is prospective and it is relatively isolated, exploration camps may be set up in the vicinity of the prospect. These camps act as both residential and work areas for the geologists and their assistants, and thus have the typical impacts of a camp set up in isolated areas; clearing of land for the camp, generation of dust, the need for a constant water supply, contamination of land by fuel spills, and the disposal of domestic rubbish and sewage are all potential impacts of such camps (Farrell & Kratzing, 1996). While this stage may be dominated by more detailed geological mapping and geophysical surveys, effective geochemical sampling may require a lightweight vehicle-mounted rig such as a rotary air blast drilling system (RAB) (Environment Australia, 1996). Thus intensive exploration requires vehicular and / or equipment access to the areas of interest. In many cases existing tracks are used for access with only minor upgrading required

(Farrell & Kratzing, 1996). The prime purpose of RAB drilling is to recover material that is representative of the bedrock (e.g. weathered, but in situ or representative soil (Environment Australia, 1996). RAB drilling is particularly suitable in well-developed weathered profile areas during advanced exploration programmes to a depth of about 50 metres. For the target selection stage, use of RAB is usually limited to a 10-metre depth (Environment Australia, 1996). Control of drilling is important, as the constant vehicular movement and the need to move the rig on a regular basis can lead to the proliferation of tracks. Vehicular movement during or just after rainfall can result in compression of the surface of such tracks, leading to conditions inhospitable to vegetation establishment and growth. Access in high rainfall areas can pose particular difficulty, and tracks can be highly visible and erode quickly unless they are properly constructed (Farrell & Kratzing, 1996). Rock chip samples collected by drilling are frequently stored in plastic bags adjacent to the drill hole, and these may remain in the environment for many months – especially those that are no longer wanted – creating unsightly scenes (Farrell & Kratzing, 1996). At times bulk samples are also collected using a backhoe or bulldozer. This work has the potential to cause extensive visible environmental impact if the trenches or costeans are left open (Farrell & Kratzing, 1996). Other impacts created during this phase of exploration include the following (Farrell & Kratzing, 1996):

- Drill holes can act as pit traps for small animals, or traps for unwary cattle and other large animals if they are left uncapped

- Diamond drill holes are frequently left with a length of plastic pipe showing as collar, and this can lead to unsightly areas if the collars are not removed following the conclusion of exploration
- Diamond drilling also frequently makes use of drilling mud to lubricate the drill bit and to prevent collapse of the hole when the drill stem is withdrawn. This mud, while mainly consisting of natural materials such as bentonite also frequently contains polymer or chemical additives which, if allowed to escape into the environment, may result in impacts such as water pollution. Again, the mud pits created, if left uncovered at the end of drilling, may result in unsightly clear ground adjacent to the drill hole. They may also take some time to dry out, becoming a hazard to wildlife until they do so

When significant minerals have been detected, more intensive study is conducted. This study, termed target testing or prospect evaluation (Environment Australia, 1996), begins with a feasibility phase which builds upon information gathered during the intensive exploration phase and involves the rigorous investigation of the prospect (Farrell & Kratzing, 1996). The feasibility phase of exploration requires the use of close-spaced percussion or diamond drilling for core or rock chip samples for delineation of a mineable ore body. The environmental impacts of such work are a scaled-up version of impacts at a prospect during the detailed exploration phase. If a potential ore body is located during this phase of exploration, bulk samples for metallurgical testing may also be taken. This may be obtained by digging trenches (costeans) or by a small-scale open pit or underground access through a small shaft or adit. In each case, the major impacts of such work are those associated with land clearance, including the development of closely-spaced grid lines and a multitude of access tracks. Waste rock from the excavation may also be stockpiled on the surface which can lead to environmental impacts in the future if, for example, precautions are not taken to characterise the potential for the formation of acid mine drainage and the subsequent leaching of heavy metals into surface and ground waters (Farrell & Kratzing, 1996). In fact, water management is frequently the most important requirement for environmental protection at such exploration sites (Farrell & Kratzing, 1996). Table 2.1 summarises the key environmental impacts associated with various exploration activities.

2.2.2 ***Mining and Production Phase***

Once the ore body has been defined, the next stage in the mineral development process is to set the stage for the development of the ore (Environment Australia, 1995a). This stage is characterised by such activities as site clearance, conveyance of construction materials and mining equipment to the mine site, mine pit construction, construction of access roads, magazines, offices, residential buildings, tailings dams, settlement ponds, fuel dumps, and the installation of mineral processing plants and other processing facilities (Environment Australia, 1995a; Farrell & Kratzing, 1996). The main problems associated with this stage of mineral development are those that characterise the constructional phase of major projects – destruction of vegetation and hence faunal habitats, air pollution and secondary impacts such as soil erosion that can cause water pollution problems. Again, during this phase, work force numbers often peak, placing strains on local accommodation. Construction workers can be transient and therefore not subject to the same social controls, and may not have the same concern for the local environment as workers from the permanent

Table 2.1: The Potential Environmental Impacts of various Exploration Activities (White et al., 1996)

EXPLORATION ACTIVITY	ENVIRONMENTAL IMPACTS							
	DISTURBANCE				POLLUTION			
	Soil	Vegetation	Fauna	Heritage	Ground	Water	Air	Noise
Airborne surveys	Z	Z	L	Z	Z	Z	L	L
Reconnaissance: Geophysics/Geochemistry	L	L	L	L	L	L	L	L
Survey gridding	L	M	L	L	L	L	L	L
Scout drilling (existing tracks)	L	M	L	L	L	L	L	M
Track construction	M	M	M	L	L	L	L	M
Target drilling	M	M	M	L	L	M	L	M
Pattern drilling	H	H	M	M	M	M/H	L	M/H
Camp construction	H	H	H	L	L	M	L	M
Costeaning	H	H	H	L	M	M	L	M
Shaft / decline construction	H	H	M/H	M	M	M	M	M/H

* Z = zero to negligible; L = low potential; M = medium potential; H = high potential

population (Environment Australia, 1995a). Prior to commissioning of the mine, an issue that sometimes arises is the need to transport bulk samples or trial shipments of mine products before the final transport infrastructure is in place. This usually involves truck transport on existing roads that have not been upgraded to cope with the demands of a new facility, which could create problems for local road users (Environment Australia, 1995a).

Exploration techniques for the location of placer deposits differ in many respects from those used for a typical hard-rock mineral exploration programme (as discussed above), as instanced (below) by Chiyanike's (1991) brief account of exploration techniques used in alluvial gold mining in Zimbabwe:

A combination of river-gradient profile analysis and aerial photography is used, to locate possible ancient as well as recent (placer gold) depositional sites. Fieldwork at a minimum usually involves trenching, pitting and augering on a grid basis to assess both the lateral and vertical distribution of the gold nuggets and flakes. While auger drilling is desirable, because it is cheaper (especially below the water table), sinking of shafts and trenching is preferred because a large sample can be recovered. The sampling pattern desired is a function of sampling method, accessibility of site and the geological situation. The uniform grid sampling pattern is usually preferred as it gives an optional statistical coverage. However, in practice, the final pattern is generally a compromise between what is conceivable and what is economical. The sample collected is usually processed in a pan, sluice or rocker box for preliminary estimates of gold. Larger samples are taken through a scaled-down production process. The main environmental impacts of the exploration phase of alluvial gold mining operations are river basin deforestation and pollution of rivers and streams (Chiyanike, 1991).

Once the necessary infrastructure has been put in place and the mine site prepared for the commencement of active mining (be it placer or hard-rock mineral exploitation), the ore is then excavated and processed to concentrate the mineral of interest (Farrell & Kratzing, 1996). This is usually a three-stage process – ore extraction, beneficiation and processing (USEPA, 1994) – which is illustrated in Figure 2.1 with gold – the mineral of interest in this study.

2.2.2.1 *Gold Ore Extraction*

In simple terms, ore extraction can be defined as the process of removing ore material from a deposit (USEPA, 1994). Gold ore extraction may be conducted using either surface or underground techniques. The mining method used is selected based on maximum ore recovery, efficiency, economy, and the character of the ore body (including dip, size, shape, and strength). Generally, gold mining is conducted using surface mining techniques in open-pit mines. This is primarily because of economic factors related to mining large-volume, low-grade ores and the improvement of cyanide leaching techniques for ore concentration during processing (USEPA, 1994). Since surface mining is the ore extraction method of interest in this study, the remaining portions of this chapter are devoted to surface gold mining techniques and processes, and their associated impacts.

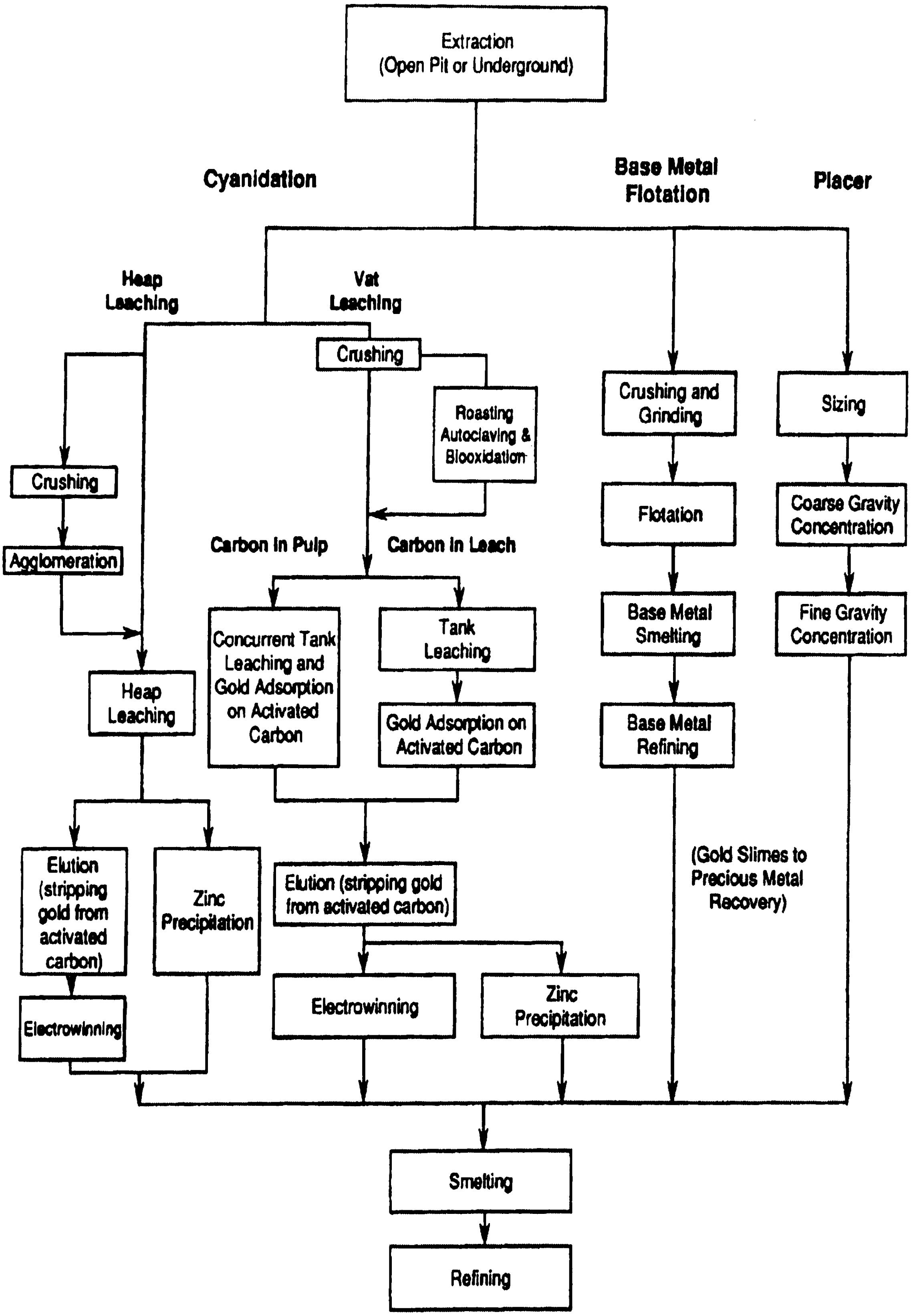

Figure 2.1: Gold Extraction & Beneficiation / Processing (USEPA, 1994)

Surface mining methods employed in the extraction of gold include open-pit and placer (USEPA, 1994). Placer mining is used to mine and concentrate gold from alluvial and sand gravels (USEPA, 1994). The nature of alluvial mineral deposits – which in turn, determines the extraction and processing techniques that have to be employed – depends on the processes that lead to their formation. For example, important gold and diamond reserves are found in alluvial fan deposits that are periodically reworked to concentrate the heavy grains. Here, uplift and / or subsidence can result in thick sedimentary accumulations containing several placer layers, as in the Witwatersrand Basin in South Africa. In contrast, the reworking of higher terraces and channel gravels may result in accumulation within a single layer, such as in the channel placer deposits found in Sierra Leone and Ghana (Thomas, 1988). In Zimbabwe, where most of the sources of alluvial gold are multi-layered placer deposits of sedimentary origin, alluvial gold mining techniques range from simple hand method using a pick-axe and dish, to mechanical operations using dam scooters, tommels and sluice boxes (Chiyanike, 1991). Dredging or non-dredging methods may be used in alluvial gold extraction (depending on the nature of the deposits) (Bogdanov & Politiuk, 1991), either of which differs appreciably from methods used in conventional hard-rock open-pit mining operations (Garnett, 1991). Compared to conventional hard-rock open pit mining – which will be discussed shortly – a gold dredging method, for instance, is characterised by the following features (Garnett, 1991):

- The commodity, gold, is of very high unit value, extremely low concentration, and often, relatively coarse. Consequently, a drillhole sample is not representative of even the very immediate vicinity of the hole. Only very large samples may be partly representative

- The deposit can be drilled to only a limited extent. The same drilling performed to evaluate a placer for dredging feasibility must suffice for mine planning and grade control. There is no equivalent to the benefit provided by the subsequent, closely spaced, blast hole data for a hard-rock deposit
- Bulk sampling by any means is often impossible before the commencement of full operations
- A dredge is the least selective of any form of mechanical mining. Typically, a dredge will work the full width of a creek or will proceed along a path approximately equal in width to twice the length of its pontoon. As the dredge advances, the width of the face can be modified within limits. The greater the depth of cut to which the dredge is digging, the less is the ability to change the face width
- Once committed to, the mining plan in the form of a dredge course rarely can be changed significantly to accommodate variations in the commodity price or in operating costs
- The treatment plant must operate at a throughput rate equal to the digging rate, with no stockpile or surge bin facilities
- Unless the dredge has been built with stripping capabilities, then whatever is excavated must be passed completely through the treatment plant
- Any attempt to work pockets of virgin ground remaining after the first mining programme involves re-excavation of all the overlying tailings

The most predominant surface mining method used to extract gold ore is open-pit (USEPA, 1994). Overburden, unconsolidated soil and consolidated rock material overlying or adjacent to the ore body is first removed, and the crude ore broken and transported to a mill or directly to a heap for beneficiation activities. Overburden and development rock (sometimes referred to as innerburden if interspersed with the ore body) may be continually removed during the life of the mine as the pit walls are cut back to permit deepening of the mine (USEPA, 1994). The depth to which the ore body is mined depends on the ore grade, nature of the overburden, and the stripping ratio. The stripping ratio is the amount of overburden that must be removed for each unit of crude ore mined and, for waste management purposes, is an indication of the amount of waste that can be produced at a particular mine. For example, with mining operations at the Brewer (gold) Mine located near Columbia (South Carolina) where the stripping ratio is approximately 1.2:1, during mining, 5,500 tonnes of ore per day (tpd) is removed together with 6,500 tpd of waste rock (USEPA, 1994).

Details of the most widely used gold ore beneficiation and processing methods are presented in Appendix 1.

2.3 **Adverse Impacts of Ore Beneficiation / Processing**

Although most of the impacts created by alluvial mining activities – as reported by Garnett (1991), Chiyanike (1991) and Bogdanov & Politiuk, (1991) – are similar to those associated with conventional surface (hard-rock) mining, the following impacts are particularly pronounced in alluvial mining operations (Chiyanike, 1991):

- River bank destruction as the miners undercut the river banks
- River bed destruction due to shaft sinking in river bed sections and dredging in flooded pools
- River course diversion as miners direct river water away from flooded pools
- Siltation of dams and rivers by the loosened sand and gravel from mining sites
- Mercury pollution mostly at the stage of amalgamation

The main problems associated with the ore beneficiation / processing phase of conventional (hard-rock) mineral production can be summarised as follows (USEPA, 1994; Farrell *et al.*, 1996): surface and ground water pollution; soil pollution / land degradation and effect on flora and fauna; air pollution; and community impacts.

2.3.1 ***Surface and Ground Water Pollution***

The primary concerns for surface and ground water at mine sites are chemical and physical contamination associated with mine operations. Acid formed by the oxidation of sulphide minerals may be a source of long-term problems at facilities that extract and beneficiate sulphide ores (USEPA, 1994). In addition to wastes, reagents such as sodium cyanide, used during beneficiation may also be released to ground and / or surface water. Mine rock dumps, disturbed areas, and haul roads may contribute sediment and increase the total solids load to surface water bodies (USEPA, 1994). Leachates containing heavy metals from mining operations and waste rock deposits may drain into nearby aquatic ecosystems, and once in streams, the heavy metals can be transported considerable distances downstream (Moore &

Luoma, 1990; Axtmann & Luoma, 1991). The impacts of mine water on aquatic environments are wide-ranging and have been considered in three categories (Jarvis and Younger, 2000):

- Chemical degradation, usually with elevated metal concentrations and low pH
- Ecological impoverishment, in some cases, rendering receiving water courses lifeless
- Aesthetic impacts, often resulting in reduced amenity value, due to deposition of iron-rich ochre

Potential mining environmental issues related to surface and ground water are discussed in more detail below.

2.3.1.1 *Acid Generation / Pollution by Heavy Metals, and Sedimentation*

The most prevalent water pollution issue in the mining industry is Acid Mine Drainage (AMD) (Hilson, 2000). AMD refers to drainage that occurs as a result of the natural oxidation of sulphide (pyritic) minerals contained in rock that is exposed to air and water (USEPA, 1994). Water percolating through mine workings or piles such as tailings or waste rock may leach sulphides from the ore and surrounding rock and result in the formation of acid drainage (USEPA, 1994). Pyritic mine spoils – spoils containing sulphide bearing minerals – decompose to produce large amounts of sulphuric acid (Voella *et al.*, 1998; Sutton & Dick, 1987), with the resulting acid sulphate spoils typically having pH of less than 4 (Logan, 1990). By reacting with rainwater, the sulphide-containing rock produces acidified runoff, contaminating both surface and ground water (Cragg *et al.*, 1995). In surface waters, if left uncontrolled, AMD creates conditions too toxic for fish and benthic invertebrates (Hilson, 2000), and can contaminate surrounding soils and threaten agricultural activities (Hilson, 2002b). Apart from waste piles, acid drainage could also originate from leaks and spillages from tailings dams or reagent ponds (Auty & Warhust, 1993) and get transferred into the environment by aerial and aqueous pathways (Herbert Jr., 1996). The acid solution may be discharged to ground or surface water, depending on the hydrology of the site (USEPA, 1994). The factor which most influences the characteristics and implications of acid drainage as a waste component is the acid generation potential of the minerals exposed in the course of mining activities. Acid production is normally associated with the oxidation of sulphide minerals, particularly pyrite (FeS_2), and pyrrhotite ($Fe_{x-1}S_x$) (Salomons, 1995). Thus the acid generation potential, as well as the potential for release of other constituents, is increased after the rock is exposed to the atmosphere (i.e., in an oxidising environment) (USEPA, 1994). Oxidation of pyrites produces two moles of H^+ initially [$FeS_2 + 7/2O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$] (Singer & Stumm, 1970). Subsequent oxidation and precipitation reactions produce additional two moles of H^+. Thus overall, the oxidation of one mole of pyrite produces four moles of H^+ [$FeS_2 + 15/4O_2 + 7/2H_2O \rightarrow Fe(OH)_3 + 2SO_4^{2-} + 4H^+$ (Paktunc, 1999)].

Oxidation of pyrrhotite (FeS) produces less acid than pyrite:

$FeS + 9/4O_2 + 5/2H_2O \rightarrow Fe(OH)_3 + SO_4^{2-} + 2H^+$ (Paktunc, 1999).

It is clear from the above reactions that pyrites and pyrrhotites can remain in their reduced state in undisturbed strata so long as they are anaerobic (Kelly, 1988). The rate of acid generation is also influenced by the presence or absence of bacteria (Kelly, 1988). Bacteria which are able to utilise pyrites as an energy source act as catalysts in the above reaction and can increase pyrite oxidation rates by up to 100 times (Paktunc, 1999). In particular, the acidophilic chemoautotrophs *Thiobacillus ferrooxidans* (iron-oxidising) and *T. thiooxidans* (sulphur-oxidising) have been found in virtually all cases of acid mine drainage (Kelly, 1988). The effect of bacteria is pH dependent; in some cases lowering of pH over time produces a favourable environment for specific bacteria, leading to accelerated acid generation, once the pH reaches the appropriate level (USEPA, 1994). Within an active mining operation, AMD can be generated from a number of sources including waste rock dumps, ore stockpiles, tailings deposits and the mine pit itself (Salomons, 1995). The prerequisite of AMD is the generation of acid at a faster rate than it can be neutralised by an alkaline material in the waste; access of oxygen and water; and a rate of precipitation higher than evapotranspiration (Salomons, 1995). Neutralisation of AMD can occur when carbonate minerals (calcite, dolomite or carbonates of Sr, Fe or Mn) are present. In the tailings deposits, some CaO is often left from the metal extraction process and it can neutralise AMD (Salomons, 1995). The combined reaction of acid generation by pyrite oxidation and neutralisation of the acid by calcium carbonate has been described by Williams (1982) as follows:

$$4\,FeS_2 + 8CaCO_3 + 15O_2 + 6H_2O \rightarrow 4Fe(OH)_3 + 8SO_4^{2-} + Ca^{2+} + CO_2$$

The above reaction shows that two moles of calcium carbonate are necessary to neutralise the acid produced by one mole of pyrite. However, the total amount of carbonate required is often not available due to the precipitation of iron hydroxide and calcium sulphate which can form coatings around the pyrite particles and prevent further neutralisation (Salomons, 1995).

In rock dumps, overburden piles, and other mine material piles that are typically unsaturated, acid drainage may start to form immediately. The acid generation potential, as well as the potential for release of other constituents [including metals and salts – (Farrell & Kratzing, 1996)], is increased in these units compared to the in-place ore body because the rock, in addition to being exposed to oxygen, is finely ground or crushed, thus presenting greater particle surface area (USEPA, 1994). Once formed, if not properly contained, this acid water can move away from the mine site and lead to pollution problems such as vegetation and fish kills in downstream waters (Farrell & Kratzing, 1996). One of the most important effects of low pH on freshwater systems is to destroy the bicarbonate buffer system, a feedback mechanism which controls the magnitude of shifts in pH. Below a pH of about 4.2 all carbonate and bicarbonate is converted to carbonic acid, which readily dissociates to water and free carbon dioxide which may be lost to the atmosphere (Kelly, 1988). There are two major effects of this: first, the water loses its capacity to buffer changes and second, many photosynthetic organisms which use bicarbonate as their inorganic carbon source may be adversely affected (Kelly, 1988). All aquatic organisms which live below pH 4.2 will need to be adapted to lack of bicarbonate, but aquatic plants, in addition, will need to be able to utilise free carbon dioxide as their inorganic carbon source for photosynthesis (Kelly, 1988).

Once destroyed, the alkalinity of a water body may take some time to recover even if no further acid is added to the system. In one instance a stream took three and a half months to recover its bicarbonate buffering system, following a pulse of acidity from a mine (Parsons, 1977).

One major problem that characterises AMD is the release of heavy metals and subsequent heavy metal pollution of aquatic and other ecological systems (Soldevilla *et al.*, 1992). Changes in acidity caused by AMD also affects availability and transport of metals (USEPA, 1994; Paktunc, 1999). Heavy metals that have been found at high concentrations in acid waters include nickel, copper, zinc, lead and arsenic (Barton, 1978; Rasmussen & Sand-Jensen, 1979; Hilson, 2000). Although trace quantities of these heavy metals occur naturally in the environment, mining and smelting processes increase their loadings to toxic levels (Hilson, 2002b). Also associated with most of these acid waters are flocs of ferric iron precipitate ('ochre' or 'yellowboy') which are composed predominantly of iron (III) hydroxide [$Fe(OH)_3$] (Clark & Crawshaw, 1979). Other flocs may also form from aluminium oxides and hydroxides and, occasionally, from other salts such as Barium Pyrite (Clark & Crawshaw, 1979). These flocs form as the acid mine drainage becomes neutralised; at very low pH values, the metal ions are soluble but as the pH rises some begin to precipitate out.

The critical pH values at which the metal ions precipitate out are about 4.3 for iron (III) and 5.2 for aluminium. As the pH of acid mine drainage is frequently below these values, the dissolved iron (III) salts will not precipitate out until a certain amount of neutralisation has taken place (Kelly, 1988). If conditions are favourable to oxidation of the pyrites and neutralisation of the drainage, this may be close to the outflow from the mine but in other cases it may not take place until much further downstream or where the acid stream joins a less acid river which can dilute the acidity and trigger the deposition of the floc (Kelly, 1988). When the pH does rise the iron (III) salts come out of solution either to form colloids suspended in the water, fine suspended particulates or heavier amorphous flocs, all of which can have severe effects on biota (Kelly, 1988). In suspension, the floc reduces light penetration and so interferes with photosynthesis and the vision of consumers. It can also cause physical abrasion (Eddlemon & Tolbert, 1983). When it settles out it can encrust rocks and stones, smothering all the benthic biota, filling gaps between stones and settling, especially in sluggish pools, to give a deep layer of enveloping deposit (Kelly, 1988).

Even after the source of acid mine drainage has been stopped, a severe spate can resuspend iron (III) deposits and, once again, affect biota for some distance downstream (Kelly, 1988). Iron (III) deposits are a major cause of turbidity in rivers and streams close to mining areas (Kelly, 1988). Suspended solids may also be produced by spoil heaps long after a mine has been abandoned, and these problems are likely to be more severe when the inhibitory effects of acid and heavy metals prevent revegetation which can reduce erosion (Kelly, 1988).

In his study of sediment supply to the Kelang River Basin (Malaysia) following past tin mining activities, Balamurugan (1991) drew the conclusion that, despite the cessation of mining activities, rivers draining mining areas still carry high sediment loads. In this particular study, it was found that sediment yield increased by three to six times after the river had passed through mining land. Without proper erosion control mechanisms installed at operating mines and at rehabilitation sites, erosion of the cleared land surface and of dumped waste material can take place leading to elevated sediment loadings in runoff during rainfall. These sediments may be transported into rivers and streams to cause pollution problems (Farrell & Kratzing, 1996). If the sediments contain metals and other contaminants that can dissolve, they can lead to even greater contamination of the aquatic ecosystem (Farrell & Kratzing, 1996). In one instance, following the collapse of a tailings dam, as much as 10,000 tonnes of waste was washed into a river (River Urumea – Spain) with a survey of the river sediment revealing high metal content including 6777 mg/kg Pb and 57,500 mg/kg Zn (Sanchez *et al.,* 1998). In a study of arsenic concentrations in soil, plant and fish samples from the Obuasi and Prestia Gold Mining areas of Ghana (Amonoo-Neizer *et al.*, 1996), it was revealed that the local environment of the mining areas had been contaminated by arsenic from mining processes. In an earlier study of arsenic pollution from the same two areas (Amonoo-Neizer & Amekor, 1993), a conclusion was drawn that none of the water bodies sampled was fit for drinking, irrigation, livestock industry or the preservation of aquatic life. Contamination of aquatic organisms, in particular, of fish, by mercury (Hg) released in the environment has been reported in various Amazonian rivers (Brazil) (Salomons, 1995). The highest Hg concentrations were found in traditional gold mining sites located in large rivers such as the Madeira River, the larger tributary of the Amazon River, where mercury concentrations up to 2.7 $\mu g\ g^{-1}$ in carnivorous fish were reported (Salomons, 1995). In Ghana, the large scale mining companies coexist with individual and small groups of miners (small scale miners) whose tools are wheelbarrows, pickaxes, shovels, steel drums, hand sieves and pans (Addy, 1998). Their activities are widespread, and often result in the introduction of mercury into the environment via an amalgamation process popularly known as 'galamsey' (Amonoo-Neizer *et al.*, 1996).

Milled tailings are another potential source of surface and ground water pollution in mining operations (USEPA, 1994). The tailings contain chemicals and residues from ore processing operations, and are characterised by high concentrations of heavy metals (Sanchez *et al.,* 1998). From the tailings impoundents, these metals, aided by acid mine drainage may be released and transported into the aquatic environment through surface water discharges and seeps (USEPA, 1994). Milled tailings are susceptible to leaching because of the increased surface area exposure of minerals not extracted during milling (USEPA, 1994).

Many underground and open-cut mines extend below the water table and therefore may require ongoing mine dewatering so that mining can proceed unhindered (Farrell & Kratzing, 1996). Dewatering can be accomplished in two ways: (i), pumping from ground water interceptor wells to lower the water table and (ii), pumping directly from the mine workings (USEPA, 1994). At the end of the mine's active life, pumping typically is stopped and the pit allowed to fill with water. Over time, depending on final hydrologic equilibrium, filling may lead to uncontrolled releases of mine water, which may be acidic and / or contaminated with metals, as well as suspended and dissolved solids (USEPA, 1994). This may cause ground and surface water pollution problems (USEPA, 1994; Farrell & Kratzing, 1996). Instances have been cited of areas where aquatic environments continued to be adversely affected many years after cessation of mining operations. They include the

Captains Flat Mine (New South Wales, Australia). Here, the collapse of two mine waste dumps several years after cessation of gold / zinc / copper mining led to pollution of the Molongo River; waste in these dumps contained significant quantities of heavy metals, and, leachate from the dumps was extremely acid – as low as pH 2.8 (Norris, 1986). Elevated levels of metals, especially zinc, were found at numerous locations down the Molongo River including a lake (Lake Burley). There was also a general decline in both the numbers and abundance of invertebrate species at many locations down the river (Norris, 1986). In his study of partitioning of heavy metals in podzol soils contaminated by mine drainage waters in Dalarna, Sweden, Herbert Jr. (1996) observed the persistence of pyrite and pyrrhotite. He observed that due to inadequate sorting methods at the time of the mine's operation, waste rock material (derived from excavation of the mine and dumped directly adjacent to the main shaft, covering an area of 1300 m^2) at the time of investigation still contained significant amounts of pyrite and pyrrhotite and some amount of chalcopyrite. It was also observed that atmospheric oxidation of these sulphide minerals and the percolation of rain water and snowmelt through the unsaturated rock dump had created a leachate plume in the groundwater, characterised by low acidity and high concentrations of Fe, SO_4^{2-} ions and heavy metals.

Mines in high rainfall environments can accumulate large volumes of water. While some of this water can be used for road watering and even in processing plants, there is frequently too much water to be able to be all used on site, and hence the excess has to be discharged into the environment. If the discharged water is laden with pollutants – especially heavy metals – receiving streams could be adversely affected (Farrell & Kratzing, 1996). Even where a mine is relatively benign with regard to heavy metals, there can be high levels of nutrients such as nitrogen in the mine water – especially in mines which use considerable quantities of nitrogen-based explosives such as ANFO (Ammonium Nitrate Fuel Oil). These elevated nutrient levels can result in blooms of unwanted algae or aquatic vegetation (Farrell & Kratzing, 1996).

2.3.1.2 *Pollution from Cyanide Solution / Residue*

Release of cyanide solutions from active leach piles or leachate collection ponds may occur during heavy storms or failures in the pile or pond liners and associated solution transfer equipment (USEPA, 1994). In addition to surface and ground water contamination, both cyanide solution collection ponds and water in the collection ditches at heap leach operations may contain cyanide and, therefore, may be potential sources of contamination for birds and other animals that come into contact with the pond (USEPA, 1994). Heap leach operations that spray or dip cyanide solution onto the flattened top of the ore heap require solution processing ponds of about 1 ha in surface area. Although not intentional or desired, puddles of various sizes may occur on the top of heaps where the highest concentrations of NaCN are found. Exposed solution recovery channels are usually constructed at the base of leach heaps. All of these cyanide-containing water bodies are hazardous to wildlife if not properly managed (Henny *et al.*, 1994).

Accidental spills of cyanide solutions into rivers and streams have produced massive kills of fish, amphibians, aquatic insects, and aquatic vegetation (Eisler *et al.*, 1999). Precious-metal waste sources of poisoning have included storage reservoirs of concentrated solutions and discharge of substances generating free HCN in the water from hydrolysis or decomposition (Leduc, 1984; Alberswerth *et al.*, 1989). Fish kills from accidental discharges of cyanide are common (Leduc, 1978; Towill *et al.*, 1989; Ripley *et al.*, 1996). In one case, mine effluents containing cyanide from a Canadian tailings pond released into a nearby creek killed more than 20,000 steelhead (*Oncorhynchus mykiss*) (Leduc *et al.*, 1982). In Colorado, overflows of 760,000 litres NaCN-contaminated water from storage ponds into natural waterways killed all aquatic life along 28 km of the Alamosa River (Alberswerth *et al.*, 1989). In October 1990, following heavy rains, 10 to 12 million gallons of cyanide solution (100 ppm cyanide) and several tons of sediment spilled into Little Fork Creek and the Lynches River in South Carolina from the Brewer Gold Mine. During the same storm, debris blocked a collection channel and caused a 420,000-gallon spill containing 170 ppm cyanide. The spill resulted in the discoloration of Little Fork Creek and fish kills for 49 miles down the Lynches River (Doyle, 1990).

Fish are the most cyanide-sensitive group of aquatic organisms tested (Eisler *et al.*, 1999). Under conditions of continuous exposure, adverse effects on swimming and reproduction usually occurred between 5 and 7.2 $\mu g\ l^{-1}$ free CN and on survival, between 20 and 70 $\mu g\ l^{-1}$ (Eisler *et al.*, 1999). Other adverse effects on fish of chronic cyanide exposure included susceptibility to predation and disrupted respiration (Eisler *et al.*, 1999). Osmoregulatory disturbances, altered growth patterns and significant reduction in relative performance (based on growth, swimming and spermatogenesis) were found to occur in fish under conditions of continuous exposure to free CN^- (Leduc *et al.*, 1982) (Figure 2.2).

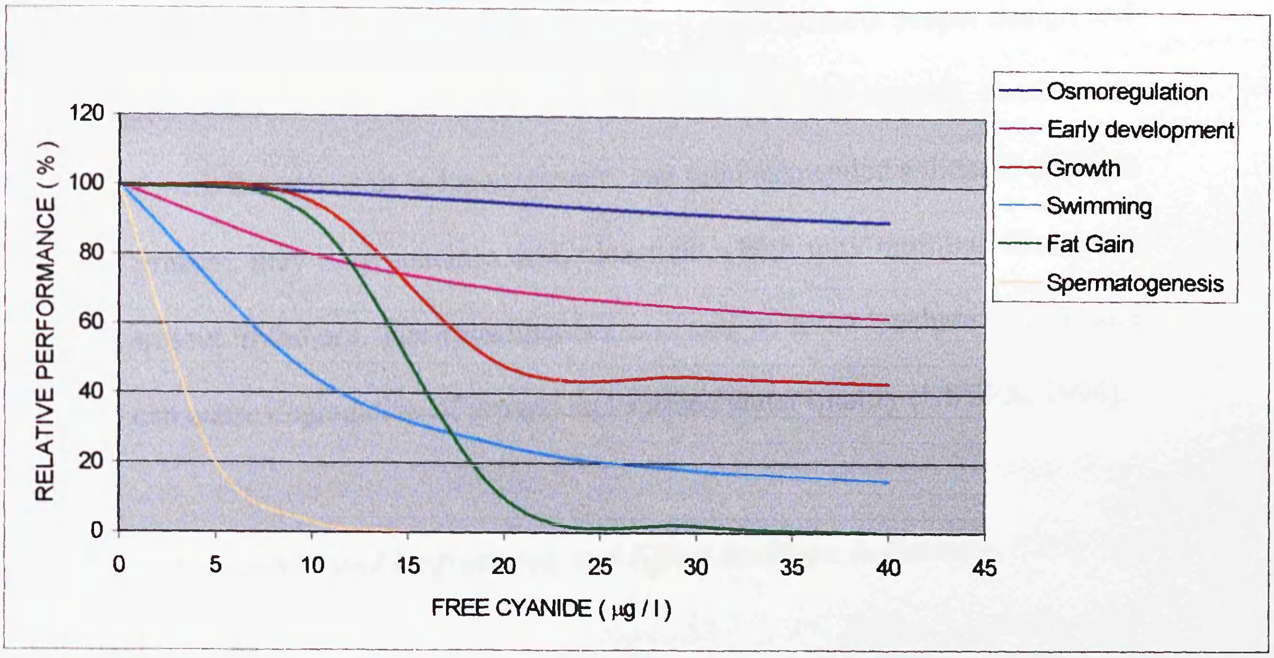

Figure 2.2: Effects of Lethal & Sub-lethal Levels of Free Cyanide on Freshwater Fish (Leduc et al., 1982)

In Arizona, a single red-breasted merganser (*Mergus serrator*) was found dead 20 km from the nearest known source of cyanide, and its pectoral muscle tissue tested positive for cyanide (Clark & Hothem, 1991). Between 1980 and 1989, 519 mammals – mostly rodents (35%) and bats (34%) – were reported as found dead at cyanide-extraction gold-mine mill tailing and heap leach ponds in California, Nevada and Arizona. Also found dead at the same ponds were 38 reptiles, 55 amphibians and 6997 birds (Clark & Hothem, 1991).

2.3.1.3 *Release from Heap Leach Piles During and After Mine Closure*

When heap leach operations are concluded, a variety of different constituents remains in the waste. These include cyanide not removed during rinsing or neutralisation, as well as heavy metals, and sulphides. After the operation has been closed or reclaimed, runoff from the spent ore may occur without proper design and construction considerations (USEPA, 1994). This runoff may contain constituents associated with the ore, such as heavy metals, and total suspended solids. If sulphide ores are present, they may generate acidic leachate which may mobilise the metals that are present in the ore. The constituents associated with the leachate (metals and arsenic) can cause degradation of ground and surface water quality (USEPA, 1994).

2.3.2 *Soil Pollution / Land Degradation and Effect on Flora & Fauna*

Three types of environmental effects are commonly associated with soils in mining areas: erosion, sedimentation and contamination (USEPA, 1994). Land disturbances and removal of vegetation related to mining activities may cause erosion and sedimentation. Under these conditions, precipitation or snowmelt may lead to soil erosion. Soil contamination may result from pollution spills associated with equipment (hydraulic oil), releases of leach solution due to liner or other equipment failure, deposition of contaminated runoff from waste rock piles, or other circumstances (USEPA, 1994).

In a study at a mining area in Gyongyosoroszi, Hungary, in which seventy soil samples were investigated, Horvath & Gruiz (1996) found contamination associated with mining operations to be most significant in areas closest to the mine. Again, metal contamination studies at an open-cast copper / sulphur mine in Southeast Ireland (Herr *et al.*, 1996) revealed that soils surrounding the mines had elevated copper and cadmium concentrations, with approximately 50 per cent of copper concentrations of investigated sites surrounding the mine exceeding acceptable limits. This led to the conclusion that contamination from the mines had spread to the surrounding area, including agricultural land. Merrington and Alloway (1994) also observed that the largest accumulation of metals outside tailings deposits was in the surrounding soils. Other studies have traced the transport of metals in mining areas directly to the soils underlying and surrounding waste deposits (Herbert, Jr., 1996), sediment and biota (Sanchez *et al.*, 1998). In these natural sinks (sediment, soil or biota) these metals may adversely affect microbial activity (Romeno *et al,* 1999), agriculture and food (Giller *et al.*, 1999), nutrient cycles (Aoyama, 1998; Lee *et al.*, 1997), wild animals (Denizeau & Marion, 1989), and human health (Pyatt & Grattan, 2001; Hilson, 2002b).

While surface mining excavations and waste rock piles are usually a source of environmental pollution when in active use, abandoned soil heaps are still subject to intermittent wind erosion carrying pollution to surrounding areas (Herr *et al.*, 1996). Historical mining and bare soil heaps from previous mine working have been found (Soldevilla *et al.*, 1992) to be a source of metal contamination in surrounding agricultural land. Many old minespoil sites have been characterised by high levels of phytotoxic iron, aluminium and manganese, with low levels of essential plant nutrients (Soldevilla *et al.*, 1992). Such sites have also been characterised by physicochemical factors such as waterlogging, accelerated run-off and erosion (Haigh, 1992).

Soils with sulphurous overburden remain vegetation-free for decades (Katzur & Haubold-Rosar, 1996). In case of extreme soil acidity (pH less than 3), $Fe(OH)_3$ is dissolved, silicates are destroyed, Fe^{3+} and Al^{3+} ions are released and heavy metals are mobilised, with seepage waters having high salt loads and heavy metal concentrations (Katzur & Haubold-Rosar, 1996). At the end of mining, extensive tracts of land can remain sterilised from future use unless rehabilitation had been integrated into the mining process (Farrell & Kratzing, 1996).

2.3.3 ***Air Pollution***

The primary sources of air contamination of mine sites are fugitive dust from mine pits and tailings impoundments (USEPA, 1994). Dust may also arise from specific activities such as blasting or simply from the movement of material around a mine site (Farrell & Kratzing, 1996). Dust can originate from all aspects of mining including removal of vegetation and soil, removal of overburden and waste rock, mining of the ore, storing of the product and placing of waste materials (Farrell & Kratzing, 1996). As tracks and roads on mine sites tend to be constructed out of waste materials, they are usually unsealed, and can act as a source of dust as vehicles pass on them (Farrell & Kratzing, 1996).

Airborne dust and gaseous emissions from mining activities can cause damage, the extent of which depends on their composition and concentration. Allegations of dust are quite common when the dust has toxic constituents, such as metallic ions. However, even non-toxic dust can contaminate if present in sufficient concentrations and this can be an issue of importance if the mine is close to population centres (Down & Stocks, 1977). Stack emissions of sulphur dioxide are the most widespread gaseous pollutant, and are normally associated with the smelting of base metal concentrates. Their principal effect is to kill or inhibit the growth of vegetation (Down & Stocks, 1977). Wind-blown dust with high metal concentrations from unvegetated spoil heaps may be deposited on soils and plants, and can enter the food chain (Herr *et al.,* 1996). Again, in the smelting process, emissions of carbon, sulphur and nitrogen compounds as well as toxic metal particulates may adversely affect air quality (Auty & Warhust, 1993). At the Ashanti Goldfields Company Limited's (AGC) Obuasi gold mine in Ghana, the processing of the ore involves a roasting process that results in the production of poisonous arsenic trioxide, sulphur dioxide and airborne particles. The discharging of the toxic oxide into the environment has led to defoliation of some areas surrounding the mine (Amonoo-Neizer *et al.*, 1996).

Although not regarded as a major impact of mining, emissions from vehicle exhausts can also be considered an impact on the atmospheric environment. As the majority of vehicles at mine sites are powered by diesel engines, poorly tuned engines can emit a considerable quantity of dark smoke, as well as combustion products from the engines themselves (Farrell & Kratzing, 1996).

2.3.4 ***Community Impacts***

It is a well-known fact that mines can generally have positive socio-economic impact on local communities. Companies often contribute to the development of key socio-economic infrastructure such as roads, hospitals, schools and housing. Moreover, the revenues accrued from mining operations contribute positively to export and foreign exchange earnings. Again, at the community level, mining projects serve as a major source of employment for local people, and trigger the rise of a wide range of small businesses such as catering, transport and cleaning services (Hilson, 2002b). However, in spite of these rewards reaped from mining projects, the land demands placed by mines often cause severe community disruption and hinder the development of other potentially profitable industries such as small-scale businesses, merchant services and small-scale fisheries. Furthermore, intensive mining can cause major environmental complications, which in turn, can render land unsuitable for a number of other important industrial applications – namely farming and forestry – after reclamation (Hilson, 2002b). Mining activities – especially those undertaken close to communities – can have various degrees of impacts on the surrounding communities (Farrell & Kratzing, 1996). Issues such as noise, dust and water pollution are frequently referred to by residents as adverse impacts (Farrell & Kratzing, 1996). Beneficial impacts such as increased employment, better facilities and the financial input to the community are not always recognised (Farrell & Kratzing, 1996).

Mining for metalliferous minerals usually results in the release to the natural environment of toxic substances, especially, metal ions and chemical reagents. This release mechanism normally continues for long periods after the mine has ceased to operate. Lethal concentrations of these pollutants could be released from the mine, which could pose potential threat to the health of humans. There is also the possibility that sub-lethal concentrations will be subjected to food chain magnification with consequent danger to human beings. The main mining impacts on communities in mining areas are associated with (Down and Stocks, 1977):

- Air and water pollution – most mining activities result in a gradual release of toxic substances, of which the most important are probably metal ions and chemical reagents. This release mechanism normally continues for long periods after the mine has ceased to operate. The wide range of liquid effluent from mining can pollute sources of water to communities in the mining area. Other effects can range from dangerous toxicity to minor turbidity affecting aquatic plants and animals at the lower end of the food chain. Periodic flooding of normal water flow may cause land pollution as a secondary effect. Even at relatively low levels, air and water pollution can interfere with wildlife and natural vegetation, discolour the atmosphere and watercourses and cause minor contamination at home, laundry, etc.
- Noise and dust – long term exposure to high noise levels can cause permanent hearing damage and similar exposure to dust can damage lung tissue and, in extreme cases, cause premature death in mine employees
- Transport – mineral transport, and particularly road traffic, poses the same threat to public safety as transport arising from other sources. Most commonly this becomes an issue of importance when a mine is established in a rural area and the volume of traffic generated considerably exceeds previous levels
- Abandoned open pit – this may fill up with water to the level of the water table. This body, surrounded by steeply sloping banks, can be dangerous if access by the general public is possible
- Ground vibrations and air blast – blasting operations give rise to ground vibrations and air blast waves, which can cause structural damage. The potential diminishes rapidly with distance from the site and commonly is limited to cracking of windows and plaster. Vibrations from static machinery do not

normally contain sufficient energy to affect property beyond the boundaries of the mine site but heavy mobile plant moving on external roads close to buildings can cause similar vibrational levels to blasting

- Damage to Property, Crops and Livestock – many aspects of mining have the potential to cause damage to buildings, animals and crops. Such damage, when it occurs, may be regarded as a direct financial loss to a member or a section of the community although it is almost inevitable that, at the levels necessary to cause damage, nuisance and loss of amenity will also occur. Problems that affect crops or livestock may also pose indirect threat to man by reducing or polluting sources of food

2.4 **Decommissioning**

During this phase, the mine site is decommissioned, facilities at the mine site are removed, works to close out waste management areas are completed, and the site returned to a state suitable for the envisaged land use (Orava & Swider, 1996). Proper planning and implementation of this phase of the mineral exploitation process is essential for (Brooks *et al.*, 1996):

- minimising environmental effects of an operation beyond its productive life
- securing lease relinquishment and release of performance bond
- maximising land-use opportunities following closure

For effective reduction of environmental impacts associated with the decommissioning process, guidelines – which set out the requirements for preparation and implementation of the decommissioning plan – need to be prepared. The guidelines should include a schedule of actions, responsibilities, resources needed and time frames (Brooks *et al.*, 1996).

Closure plans and performance criteria need to be developed in the early stages of facility design, and then verified and updated periodically through the operating life of the facility in preparation for decommissioning and closure (The Mining Association of Canada, 1998). In fact, planning for decommissioning should commence at the same time as project planning, in order to avoid any restriction of options in the future. The decommissioning plan has to be reviewed regularly as the operation matures and issues can be resolved with greater certainty (Brooks *et al.*, 1996). It is important for the decommissioning plan to be integrated with operations plan, as actions taken during operations can have a significant effect on the requirements for decommissioning, even to the point of severely restricting options available for final closure (Brooks *et al.*, 1996).

Minimisation of adverse impacts associated with the other phases of the mining process is discussed below.

2.5 Minimisation of Adverse Impacts of Surface Mining

2.5.1 *Introduction*

Although surface mining by its very nature creates a myriad of both environmental and social problems, through appropriate mitigation measures, these problems could be reduced to acceptable limits (Cragg *et al.*, 1995). This calls for effective planning in all aspects of the mining process, taking into account environmental protection, cultural, social, economic, religious and land use impacts as well as safety measures (Cragg *et al.*, 1995). Approaches to minimising the impacts of mining have included the use of environmental management regulations and controls (Bradfield *et al*, 1996) and, appropriate environmental management techniques and technologies (Forey & Grubler, 1996; Warhurst & Bridge, 1996). These environmental management tools are discussed below.

2.5.2 ***Use of Environmental Regulations and Controls***

Over the years, environmental regulations and standards have been used worldwide as a tool for minimising mining impacts. In fact, environmental regulatory and standards policy can fundamentally promote the innovative performance of firms (Forey & Grubler, 1996). In the U. K., environmental regulation is founded on two approaches: (i), technology-based standards concentrating on the originator of pollution, in the forms of standards that the polluter can achieve, e.g., water quality standards, and (ii), environmental quality standards or the general quality standards of the receiving media, i.e., the ambient levels of pollution (Ryall & Pinder, 1994).

Unfortunately, more often than not, environmental regulation in developing countries is of the command and control type and usually deals with symptoms of pollution once reported, and not the causes of environmental mismanagement from the outset (Auty and Warhurst, 1993). Meanwhile, in the industrialised countries, emphasis has moved away from the 'pollutee suffers' to one in which the 'polluter pays', whereby the polluter is charged for destructive use equal to the damage caused. Again, the use of market-driven measures including taxes, emission charges and deposit funded systems such as the posting of bonds up front for the rehabilitation of mines after closure, has been employed to enhance environmental sustainability of mining ventures in many industrialised nations (Auty and Warhurst, 1993). In West Europe and North America, environmental regulations that prohibit the disposal of contaminated material without prior treatment have encouraged the development of new treatment techniques for soil decontamination (Papassiopi *et al.*, 1997). In California, the Surface Mining and Reclamation Act of 1975 (SMARA), with subsequent amendments, is the principal instrument for regulating gravel mining. SMARA designates lead agencies to carry out the main provisions of the act. Among other things, extractors are to submit to the lead agencies, a 'reclamation plan' describing the existing environment, the intended ultimate reclamation of the site, and the manner in which adverse environmental impacts will be prevented or minimised (Kondolf, 1994).

In mineral exploitation in the UK, an integrated and phased scheme of working and restoration has to be agreed with the mineral planning authority before any operations begin on the site. The scheme must outline how worked-out areas are to be progressively restored as extraction proceeds through the rest of the site. It should also indicate the expected soil movements, either direct from an area being stripped to an area being restored or involving temporary storage, and should provide details of soil resources and the means of handling them (McRae, 1989). In Malaysia, mining legislation includes strict environmental regulations such as this: 'No occupier of mining land shall allow effluent water from any mining area under his control to discharge into any river or natural water-course or otherwise pass beyond his control where such effluent water contains solid matter in excess of set limits'. In addition to the strict effluent quality regulation, the Department of Mine's enforcement programme includes a complete permit system whereby the applicant to get his licence has to show clearly his proposed plan for containing silt run-off. Again, all leases include the requirement for miners to put up a sizeable bond (to the Land Department) to ensure that miners, after completing mining, will level off and resurface the worked area with grass (Balamurugan, 1991).

Australia's uranium mining industry strictly follows the perspective of an 'ecologically sustainable development' which does not allow for long-term pollution and requires the placement of bonds to cover all the costs of rehabilitation according to the designated future use of the land (Förstner, 1999). Within the Commonwealth of Australia, the Federal government plays largely an advisory role through its publications on best practice in environmental management. Taking this into consideration, each state government then develops and applies its own set of environmental guidelines. In reality, most of these guidelines are effectively requirements (Maxwell & Govindarajalu, 1999). For instance, at the exploration stage of mining, operators in each state must consider 'guidelines' with respect to:

- Location and layout
- Timetables for operations including the development of associated infrastructure, land clearing, extraction operations, and haulage
- Land management
- Water management

- Land rehabilitation

With development of the extraction and beneficiation stages, key issues that need to be addressed include (Maxwell & Govindarajalu, 1999):

- Atmospheric emissions
- Waste rock management
- Tailings dams
- Revegetation
- Land rehabilitation

In the Shanxi province of China, fees for land restoration and forest conservation are levied before land is assigned to mining in order to guarantee that environmental protection can be paid for (Miao & Marrs, 2000). Restoration of the degraded areas is carried out by a designated organisation or by the polluters themselves. The Municipal Land Bureau, the Mining Group and the Department of Land Expropriation must sign the reclamation contract. At this point an advance fee for land reclamation must be paid to the appropriate agencies in advance of mining. Once restoration of the degraded areas meets an agreed state assessment standard, the advance is reimbursed for (Miao & Marrs, 2000).

2.5.2.1 *Laws & Regulations on Mining in Ghana*

Although several Acts, Ordinances and Regulations have been enacted by the various governments of Ghana since 1900, very few of them make provision for environmental protection (Kesse, 1985). In fact, only the Mining Regulation, 1950, Mining Regulation, 1970 and the Mining and Mineral Law, 1986 [Government of Ghana Law 153] make provision for environmental protection, as outlined below:

i. *Mining Regulation, 1950 (Government of Ghana, 1950)*

Under this regulation, it is mandatory for mining companies to take measures like levelling and fencing of excavations and pits to improve the landscape and prevent accidents. While Sections 3 and 4 of the Regulation make adequate provision for landscape improvement and prevention of accidents at mine sites, section 6 of the Regulation empowers Mines Inspectors to cause a concession holder to take measures to ensure public safety at the mines. Section 7 of the Regulation further confers powers on the Chief Inspector of Mines, by non-compliance of the Regulation, to undertake measures to ensure public safety. Section 8 of the Regulation calls for the protection of polluted waters from human use through fencing and erection of white boards, etc., by the mining company.

ii. *Mining Regulation, 1970 (Government of Ghana, 1970)*

Apart from safety measures, water pollution prevention and maintenance of appropriate sanitary conditions that appear in almost all other mining regulations, Section 52 of the above regulation obliges mining companies to 'clear back all trees at or near the top or sides of surface working to avoid danger from falls'.

iii. *Mining and Mineral Law, 1986 (Government of Ghana, 1986)*

Under Section 17, Sub-section 53 of this law, applicants for grant, revocation suspension or renewal of mineral right are obliged to 'forward copies of the application to the Minerals Commission, the Lands Commission, the Forestry Commission (in cases where forestry resources are to be affected by the mineral exploitation envisaged) and the Public Agreement Board'. These authorities must be satisfied that mining operations will not have undue adverse environmental and social consequences before mining can proceed. Section 46, Sub-section 4(6) of the Law states: 'A mining lease shall not be granted to an applicant unless the proposed programme of mining operation submitted by him takes proper account of environment safety factors'. Again, Section 72 of the law emphasises that 'the holder of a mineral right shall in the exercise of his right under the licence or lease have due regard to the effect of the mineral operations on the environment and shall take such steps as may be necessary to prevent pollution of the environment as a result of such mineral operation'.

A careful examination of the provisions made for environmental protection in the Minerals and Mining Law, 1986 reveals they do not spell out any penalties for mining-related environmental offences making them (provisions) less deterrent and ineffective for environmental protection.

The Environmental Protection Agency Act, 1994 (Act 490) is the only effective legal tool in Ghana with provisions that offer appreciable environmental protection in mining areas. Section 12, Sub-section 1 of the Act makes it obligatory for all major projects (including 'large scale' mining) to be registered with the Environmental Protection Agency. All large-scale mining companies are also obliged to undertake EIA studies on their project site and surroundings, and submit the associated Environmental Impact Statement (EIS) to the EPA for scrutiny. A provisional permit may be given for the commencement of operations when EPA is satisfied with the EIA study, especially predicted impacts and proposed impact mitigation measures. The provisional permit is regularised within two years of its issuance and project commissioning subject to:

- Satisfactory commencement of development, operation and performance review
- Observance of relevant approval conditions
- Compliance with mitigation and other impact management measures

In a recent study, Appiah-Opoku (2001) stresses how mining companies in Ghana are working hard to improve their environmental performance in order to fulfil the conditions above, and to have their provisional permits regularised.

An important aspect of the Ghanaian EIA process worth mentioning is participation by local authorities and members of the general public. Where a draft EIS is found to be acceptable, the EPA sends copies to the appropriate local authority to be made accessible to stakeholders in their area. The EPA, through newspaper advertisements and postings at appropriate public places, gives a 21-day public notice of the final EIS. If a strong public concern over the proposed undertaken is expressed, the EPA appoints a panel of three to five persons to hold public hearings and gather information on the concerns of the public and how best the concerns could be addressed. At least two-thirds of the panel members must be residents of the geographic area where the project will be undertaken. Appiah-Opoku (2001) sees the above public participation process associated with the Ghanaian EIA system as a major breakthrough in the EIA process in Ghana. He however fails to outline aspects of the public participation process that need to be improved upon. Currently, the public has the chance to participate in the EIA process only after the EIA study has been undertaken and the associated EIS has been produced by the project proponent. In fact, public input before, during and after the EIA study would be more appropriate in the Ghanaian context, where many industrial projects – such as large-scale mining – are sited close to communities. In Indonesia for instance, public participation in the EIA process occurs *before* the commencement of the EIA studies, and during preparation of the Terms of Reference (TOR) for the EIA study. Again, when the TOR are presented to the EIA Commission, the public gains another opportunity to provide some input through its public representative who sits on the EIA Commission (Purnama, 2003). Based on the recommendations resulting from the TOR review and input from the public, the proponent then prepares the EIS and Environmental Management Programmes (EMPs). After all EIA documents have been prepared, the proponent presents the documents to the EIA Commission for further review. Ahead of the review process, members of the public have one more opportunity to express their responses and suggestions (Purnama, 2003).

It must be stated that the effectiveness of Ghana's EPA Act 1994 (Act 490) in ensuring optimum environmental protection in mining areas is 'masked' from time to time in some mining areas by the provisions of an earlier mining law – the 'Small Scale Gold Mining Law 1989 [Government of Ghana Law 218] (Government of Ghana, 1989). Under this Law, 'Small Scale' Gold Mining Ventures (i.e. ventures with concession areas less than 10 ha) are not to be registered with the Environmental Protection Agency. Rather, they are to be registered with the Minerals Commission for a licence, and, the Mines Department for an operating permit. The problem with this procedure has been lack of effective monitoring which results in environmental degradation, soil and water pollution in areas where such mining operations are prevalent. Ghana can learn from Nigeria's approach to regulating small-scale mining operations. In Nigeria, the EIA system 'accommodates' small-scale mining operations. Here, EIA is mandatory for all 'Category 1' projects, which include mining of materials in new areas, irrespective of the size of the project area, and processing of ores of aluminium, copper, gold or tantalum when the area of activity is at least 250 hectares (Olokesusi, 1998). 'Category 2' projects, which include small-scale mining operations, are treated as 'Category 1' projects if they are located in or close to environmentally sensitive areas. These areas include: coral reefs; mangrove swamps; tropical rain forests; areas with erosion-prone soils (e.g. mountain slopes); areas of particular historical or archaeological interest; and natural conservation areas (Olokesusi, 1998). An important aspect of the Nigerian EIA process worth mentioning is that although a full-scale EIA may not be mandatory for 'Category 2' projects that are not located in an environmentally sensitive area, a *partial* EIA is required. In this case, mitigation measures or changes in project design (depending on the nature of the environmental impacts) may also be required from the proponent. This approach to EIA differs greatly from what is in place in Ghana where small-scale mining ventures (operations covering less than 10 hectares) are not EIA mandatory and are neither registered with nor monitored by the EPA.

The Environmental Protection Agency and the Minerals Commission of Ghana (1994) have jointly published some guidelines for environmental protection applicable to both established and recently constructed mines. The guidelines are divided into three parts:

- General guidelines for exploration, mining, mineral processing and decomissioning
- Detailed guidelines for conducting Environmental Impact Assessment and the preparation of Environmental Impact Statement
- Detailed guidelines for the preparation of Environmental Action Plans for existing mines

Among other requirements, the environmental management programmes based on the above guidelines should 'include a description of a Rehabilitation Plan' (EPA Ghana & Minerals Commission, 1994).

One of the key objectives of the guidelines described above is to pre-empt permanent environmental damage by mining companies, in order to promote sound environmental stewardship (EPA of Ghana and Minerals Commission, 1994; Domfe, 2003). In order to achieve this objective in the mining sector, mining companies have to demonstrate that their activities have been planned in an environmentally sensitive manner and that appropriate pre-emptive or impact-mitigation measures and safeguards have been integrated into the project design (Domfe, 2003). Again, under the guidelines, new mines that cover an area of at least 10 hectares are expected to conduct EIAs to ensure that modern, pre-emptive environmental controls are built into the design of new mining projects during the planning phase. However, in the case of mines existing before the introduction of the

Mining and Environmental Guidelines, mines are to prepare Environmental Action Plans (EAPs) to be implemented alongside production (Domfe, 2003).

2.5.2.2 *Impact of Environmental Regulations*

For some companies, regulation has provided the incentive to invest in new processes which are able to lower production costs overall. For example, in response to a condition of permitting, the Coeur d'Alene mining company developed a cyanide recovery technology (Cyanisorb) to recover cyanide from its tailings pond. As a proprietary technique, Cyanisorb has become a marketable product for the company (Warhurst & Bridge 1996). The threat of a substantial fine in anticipation of acid mine drainage from low-grade waste dumps at Exxon's Los Bronces mine in Chile, led the company to seek alternative solutions. The fine provided an economic justification for the development of a bioleaching equipment that was able to extract copper profitably from the waste dumps while preventing water quality degradation (Warhurst & Bridge 1996). Noranda Minerals Inc., for example, in response to regulations on permissible SO_2 emission levels reduced SO_2 emissions at its seven metallurgical facilities from 800,000 tonnes per year in 1970 to 270,000 tonnes per year in 1990. This was achieved by adopting smelter technologies that reduce SO_2 production, and by increasing its conversion to sulphuric acid which is sold as a by-product (Warhurst & Bridge 1996).

Although it has been argued (Ryall & Pinder, 1994) that the backbone of environmental control is the use of legal controls, there is evidence (e.g., Bradfield *et al.,* 1996) to suggest that in most situations, this may not be the best approach as far as excellence in environmental management by industry is concerned. To achieve best practice in regulation would appear to require some move away from prescription-based legislation relying on the traditional 'Command and Control' approach. In the old type approach to regulation, techniques to be employed by industry are prescribed by the regulator, who then has the responsibility for industry inspection to ensure that the prescribed methods have been adopted. A range of penalties in which the level of penalty reflected the severity of breach often supported such regimes. For the most part, offences had to be enforced through the courts. Mitigating circumstances were often taken into consideration at the courts, weakening the effectiveness of the penalty and not necessarily achieving the required outcome (Bradfield *et al.*, 1996). In their assessment of the effectiveness of environmental regulations governing alluvial mining in developing countries – with a particular focus on Guinea (West Africa) – Harcourt-Richards & McCracken (1991) drew the following conclusion among others: ' Environmental codes in Third World Countries have a tendency to be vague – they could be interpreted as being very strict or otherwise as being able to be manipulated to suit more pressing need of development of the resources at some expense to the local government.' Describing the situation in Guinea, the authors stressed the lack of provision – in legal regulations by Ministerial Authorities – for ongoing compliance monitoring to ensure that effluents continue to be treated. Another problem about the regulations observed (Harcourt-Richards & McCracken 1991) was the non-deterrent nature of penalties for 'not restoring a site or for infringing the regulations regarding the disposal of waste' (each of which attracted fines of between 15,000FG and 1,000,000FG [£14 to £952 at May 1989 exchange rates]) and / or 3 months to 5 years imprisonment.

It is clear from the examples above that although legal controls could be useful in many situations, the way forward, as far as minimisation of environmental problems created by industry is concerned, is strategic environmental management by industry. In fact, satisfactory environmental performance is achieved more readily when ownership of the environmental consequences of a company's activities becomes part of the organisational culture (Brooks *et al.*, 1996). The next section discusses various environmental management approaches to minimising mining environmental impacts.

2.5.3 *The Environmental Management Approach*

Proven approaches to mitigating adverse impacts of surface mining have included the use of environmentally friendly technologies and techniques at various stages of the mining process (Foray & Grubler, 1996; Warhurst & Bridge, 1996). For instance, the most effective way to reduce mining-related dust pollution is to control dust formation by controlling the moisture content at source – an 8 to 10 per cent moisture content, for instance, prevents dust emission from sulphide ore concentrates (Herr *et al.*, 1996). In their study on evaluation of heavy metal remediation using mineral apatite, Chen *et al.* (1997) observed that North Carolina Mineral Apatite was effective in removing dissolved Pb, Cd and Zn leached from contaminated soil. It was phenomenal in their experiments (using the Toxicity Characteristic Leaching Procedure) that apatite was able to reduce the metal concentrations to below U.S. EPA maximum allowable levels and thus suggesting that apatite could be used as a cost-effective option for salvaging metal-contaminated soil and / or water. Oxalate (Ox) has also been successfully used (Elliott & Shastri, 1999) to decontaminate soils with elevated levels of zinc (2,700-mg kg^{-1} Zn) in Palmerton, Pennsylvania, and lead (2000 mg kg^{-1} Pb) in Indianapolis, Indiana. Techniques for minimising environmental pollution from mercury include the use of hydraulic traps, which reduces metallic mercury output by about 90%, and the use of distillation retorts to reduce mercury vapour emission to the atmosphere (Grosser *et al.*, 1994). Various techniques have been employed in the past to improve the conditions of soil disturbed by surface mining including improvement in drainage (Hodgkinson, 1989) and pH conditions (Perkins & Vann, 1995). There are also techniques for the restoration of mineral workings to agriculture, forestry and other uses (McRae, 1989). The BIOX process, pioneered by Gencor and first used in its Fairview mine in South Africa, has been successfully used to reduce arsenic trioxide and sulphur dioxide emissions to acceptable limits (Warhurst & Bridge, 1996). The BIOX process involves biological oxidation of sulphide mineral deposits. Ore is crushed to liberate sulphide minerals from the gangue, then floated to produce a concentrate. The concentrate is fed to slurry tanks containing bacteria (*Thiobacillus ferooxidans*) in which temperature, oxygen and pH conditions are controlled to achieve an optimum rate of reproduction. Average residence time for the slurry is four to five days, after which it is thickened and treated in a conventional cyanidation plant. Arsenic in the ore is recovered in the solution from the thickeners and precipitated as inert and environmentally stable ferric arsenate suitable for tailings disposal (Warhurst & Bridge, 1996). The advantages of the process over conventional treatments are its reduced capital and operating cost, improved recovery rates which are not constrained by grade, and very robust bacteria able to withstand considerable variations in ambient conditions. The replacement of roasters with the BIOX process at Fairview has contributed significantly to solving the problems of sulphur dioxide and arsenic trioxide pollution (Warhurst & Bridge, 1996).

Both limestone and organic matter may be used to reduce the negative effects of acid soil conditions on plant growth. In this case, while lime increases adsorption and precipitation of toxic metals (Logan, 1990; Kuyucak, 1998), it also increases nutrient availability and enhances biological activity (Logan, 1990). Organic matter, on the other hand, buffers soil pH, binds toxic metals and improves soil properties such as water holding capacity (Logan, 1990). This, notwithstanding, lime application may have limited application in humid tropical environments where, under the particular weathering and soil drainage regimes, alkalis and alkaline materials are almost completely leached (Reading *et al.*, 1995). Again, incorporation of ameliorants evenly into rocky spoil is difficult as the liming effect diminishes as sulphide continues to oxidise. This, coupled with the fact that neutral material overlying acid spoil can become acidified through capillary movement of acid water, makes it necessary to give due consideration to tolerance to acidic soil conditions as well as response to amendments when selecting species for revegetation of mine sites that have acid-generating spoils (Dent, 1992). Thus, successful reclamation of acid mine sites may be enhanced by revegetating with species that are tolerant to acid mine conditions (Voella *et al.*, 1998). To reduce arsenic pollution, a useful method is to dump tailings from preconcentrate treatment separately. These tailings contain the most significant quantities of arsenopyrite and other sulphide-containing minerals. Due to weathering, arsenic is set free, but because of the acid milieu, it is directly immobilised as scorodite – $Fe^{3+}(AsO_4).2H_2O$ (Grosser *et al.*, 1994). In fact, research

(Craw *et al.* 2000) has found a direct relationship between scorodite formation and attenuation of arsenic concentration.

Around some gold mines in East Otago, New Zealand, although the release of arsenic into the environment had been occurring over a long period as a result of mining-accelerated decomposition of arsenopyrite in gold-bearing veins, studies conducted on old mine adits and wetlands created from old tailings dams (Craw *et al.*, 2000) revealed unusually low arsenic concentrations at most sampling sites. In most of the sampling sites, dissolved arsenic never exceeded a few parts per million, a typical value being 0.75 ppm. It was however discovered that some of the sampling points had 'arsenic' concentrations of up to 33,000 ppm principally in the form of the secondary arsenic mineral scorodite. The researchers also found that arsenic concentrations were directly related to pH, with maximum arsenic concentrations occurring at relatively alkaline sites. A conclusion was then drawn that deposition of scorodite limited arsenic discharge into waterways, particularly at low pH.

The sections below outline various Best Practice Environmental Management (BPEM) approaches to minimising adverse mining impacts extracted from Environment Australia's BPEM in Mining Modules. It must be stated that currently, these modules offer the most comprehensive and adaptable guide on BPEM in mining, as explained in Chapter 7.1 of this thesis.

2.5.3.1 *Mine Planning for Environmental Protection*

As the mineral development process moves from the concept design stage through to operation and eventually to decommissioning, proper planning can reduce environmental impacts, result in good environmental performance, and enhance the public perception of the industry as able to operate in an ecologically sustainable way (Environment Australia, 1995a). The first step in planning is to recognise the environmental issues that need to be addressed in the mining area, which should result in the design of a feasible mine layout. Successful mine planning for environmental protection avoids or minimises potentially adverse environmental impacts over the life of the mine and into the future by carefully considering the layout and design of the various components of the mine. The process must integrate community expectations and concerns, government requirements and profitability of the mining project, while minimising environmental impacts (Environment Australia, 1995a). Before mine planning can commence, planners need an adequate understanding of the resource deposit. They also need to understand the surrounding environment through programmes of baseline environmental monitoring and data collection in order to identify particular features, attributes and constraints that need to be considered in mine planning. Conventionally, the baseline data should be collected over 12 months to account for seasonal variations. If the mine is a major development, or the surrounding environment is particularly sensitive, it is highly desirable to collect data for as long as possible, extending over at least three years (Environment Australia, 1995a).

Other considerations for 'Mine Planning for Environmental Protection' along the lines of BPEM (Environment Australia, 1995a) are described in Appendix 2.

2.5.3.2 *Community Consultation & Involvement*

BPEM for mineral resource explorers and developers includes involving the community by talking to people about all aspects of the proposed project, and by listening to their concerns, their needs and suggestions (Environment Australia, 1995b). The approach for doing this is described in detail in Appendix 3.

2.5.3.3 *Environmental Impact Assessment*

Environmental Impact Assessment (EIA) is the process in which environmental factors are integrated into project planning and decision making in a way that is consistent with ecologically sustainable development. In mining operations, EIA helps to protect the environment by looking at the likely environmental effects of impacts from all stages of the mining project from exploration and planning, through construction, operations, decommissioning and beyond site closure. It also enables the developer, community and government authorities to work together in dealing with project impacts (Environment Australia, 1995c). EIA, in the context of BPEM in Mining (Environment Australia, 1995c) is presented in Appendix 4.

2.5.3.4 *Exploration Techniques*

Well-planned and managed exploration activities should have a minimal environmental impact and restore the mine site, as much as possible, to its original condition. This requires environmental planning and management to produce exploration programmes that: involve affected communities in developing work programmes and determining outcomes; protect the environment outside exploration areas; avoid or minimise disturbance and contamination within exploration areas; and restore areas after exploration (Environment Australia, 1996).

Most of the problems associated with exploration (e.g. machinery noise, dust, land and waterway disturbance, disturbance of fauna and disruption to other land users) result from poor management practices such as (Environment Australia, 1996):

- failure to fill or make safe trenches (costeans) dug to sample soil layers
- unnecessary or excessive clearing of local vegetation prior to exploration activity
- inadequate controls on fuel or fluids used in drilling
- failure to cap and make safe drill holes
- unnecessary cutting of access tracks
- allowing transport of weeds or other exotic species and plant diseases between regions

BPEM strategies for minimising the effects of exploration activities of mining projects (Environment Australia, 1996) are described in detail in Appendix 5.

2.5.3.5 *Dust Control*

The control of dust must be a fundamental part of any environmental management plan because of the increasing public awareness of human health issues and expectations of environmental performance, and the duty of care required of mine operators by government and the community (Environment Australia, 1998a). This calls for the adoption of a dust management system which recognises and responds to the issues of dust emissions at all stages of mining from mine planning and operation through to mine closure. This includes systematically identifying sources, predicting dust levels, evaluating potential effects on human health and the environment, and incorporating prediction and control measures (Environment Australia, 1998a). Details of BPEM measures for effective dust control (Environment Austrlia 1998a; 2000) are presented in Appendix 6.

2.5.3.6 *Water Management*

The fundamental prerequisite for best practice minesite water management is recognising the need to develop and implement a comprehensive and co-ordinated minesite water management plan (MWMP). This and other Best Practice approaches for effective minesite water management (Environment Australia, 1999) are described in detail in Appendix 7.

2.5.3.7 *Noise, Vibration & Blast Control*

Good planning is essential to mitigate noise, vibration and airblast impacts, which might otherwise lead to unacceptable effects on the community or the natural environment. Effective management of noise, vibration and airblast calls for noise, vibration and airblast impact assessment, and the design of control measures for vibrations and airblasts along the lines of BPEM (Environment Australia, 1998b), as outlined in Appendix 8.

2.5.3.8 Cyanide Management

Cyanide has been used safely and effectively in the mining industry for many years, but it is a dangerous chemical that must always be used with caution. Best practice cyanide management should be planned from the time of mine conception to closure (Environment Australia, 1998c), as outlined in Appendix 9.

2.5.3.9 *Tailings Containment*

Tailings from the mining industry are most commonly finely ground material left over after the valuable metal has been extracted. The three major concerns associated with tailings are (Environment Australia, 1995d):

- the structural stability of the tailings dam and the possible release, should failure occur, of a large volume of water and semi-fluid tailings – such an event would not only cause extensive downstream pollution, but could also pose a threat to life and property depending on the dam's location

- the impact the tailings operation might have on the lifestyle of people living in the immediate area – this might include nuisance from dust, noise pollution (during dam construction, repair, etc.), radiation, the visual impact of a large engineered structure and the effect on local property values
- the pollution potential for ground and surface water – both short and long term

Some recommended Best Practice tailings management strategies (Environment Australia, 1995d) are outlined in Appendix 10.

2.5.3.10 *Management of Sulphidic Mine Waste & Acid Drainage*

The problem of acid drainage encompasses all issues associated with the actual and potential effects of sulphide oxidation resulting from mining activities. Once established in mining wastes such as waste rock stockpiles or tailings impoundments, acid drainage may persist for tens to hundreds of years and be difficult and costly to remediate (Environment Australia, 1997). Increased mobility of dissolved metals is an associated problem which may occur even when the rate of sulphide oxidation does not result in net acid drainage (Environment Australia, 1997).

While evaluation of minesite prevention and remediation strategies is an on-going process, there are a number of well-established best practice principles for minimising acid drainage, as outlined in Appendix 11.

2.5.3.11 *Environmental Monitoring & Performance*

Environmental monitoring provides the information for periodic review and alteration of the environmental management plan as necessary, ensuring that environmental protection is optimised at all stages of the mining project through best practice. In this way undesirable environmental impacts will be detected early and remedied effectively (Environment Australia, 1995e). It will also demonstrate compliance with regulatory requirements. Environmental monitoring should be directed to key environmental issues such as (Environment Australia, 1995e):

- Developing improved practices and procedures for environmental protection
- Detecting short and long term trends in environmental quality
- Recognising environmental changes to enable analysis of their causes
- Measurement of environmental impacts
- Checking the accuracy of predicted impacts
- Developing improved monitoring systems
- Providing information on the impact of mining activities

The diversity of climates, ecosystems, land uses and topographies greatly influences the design of environmental monitoring programmes. BPEM for each site is therefore governed by these regional, physical and social factors. Various approaches for designing and implementing BPEM minesite monitoring programmes (Environment Australia, 1995e; 2000) are described in detail in Appendix 12.

2.5.3.12 *Rehabilitation & Revegetation*

Surface mining results in the destruction of the existing vegetation and soil profile (Environment Australia, 1995f). Removal of overburden and waste rock and their replacement in the mined out pit can significantly change the topography and stability of the landscape. Some overburdens may release salts, or contain sulphidic material which can generate acid mine drainage. These materials can sometimes be selectively placed so that they do not cause problems, or they may require special rehabilitation treatments (Environment Australia, 1995f). Depending on the agreed appropriate post-mining landuse, research may be necessary to define species selection, the ecology of native species and seed biology, plant establishment techniques, plant symbioses, and a range of other issues that ensure the success of the rehabilitation strategy. The main principles of Best Practice minesite rehabilitation / revegetation (Environment Australia, 1995f) are described in detail in Appendix 13.

CHAPTER THREE

METHODS OF DATA COLLECTION

3.1 Introduction

The approach used for data collection in this study comprised a field survey involving the three main stakeholders connected with mining activities in the study area, viz :

i. Selected mining companies – the main beneficiaries of mining operations
ii. Rural communities in the study area which are both negatively and positively affected by mining operations
iii. Public institutions, including those responsible for regulations / standards governing mining activities in Ghana (e.g., the Environmental Protection Agency, Minerals Commission and the Mines Department) and those which through research and other activities, are familiar with the environmental and socio-economic impacts of surface mining in Ghana (e.g., the academic institutions)

Four mining areas in southern Ghana were selected and studies conducted on the environmental and socio-economic impacts created, and the environmental management programmes operated, by the four mining companies operating there. The types, adequacy and appropriateness of the environmental management programmes operated by the mining companies were studied using a questionnaire and through mine site visits. Again, using different sets of questionnaires, a cross-section of the community including farmers, fishermen, hunters and housewives were also interviewed to ascertain their perception of mining activities on their environment and socio-economic lives. Perceptions (e.g., Burger and Sanchez, 1999) and narratives (e.g., Robertson *et al.,* 2000) of local communities have been used in the past, in the design of strategies for the rehabilitation of degraded landscapes. In addition to collecting information from the above sources, discussions were also held with, and relevant data obtained from, some government organisations and research institutions found to be associated or familiar with mining activities in Ghana in one way or the other.

3.2. **Selection of Study Areas**

The study area (Figure 3.1) is located in the section of southern Ghana where more than 70% of the gold annually produced in the country (Ghana Chamber of Mines, 1999) is obtained. Apart from the area's significance as a major producer of gold in Ghana, most of the mining companies there (including the four companies selected for this study) obtain the bulk of their ore through surface mining, the mineral extraction method of interest in this study. The main features of research interest characteristic of the four selected mines were as follows:

- Mining operations spanning several generations – the case of Ashanti Goldfields Company (AGC) Limited's gold mine in the Obuasi area

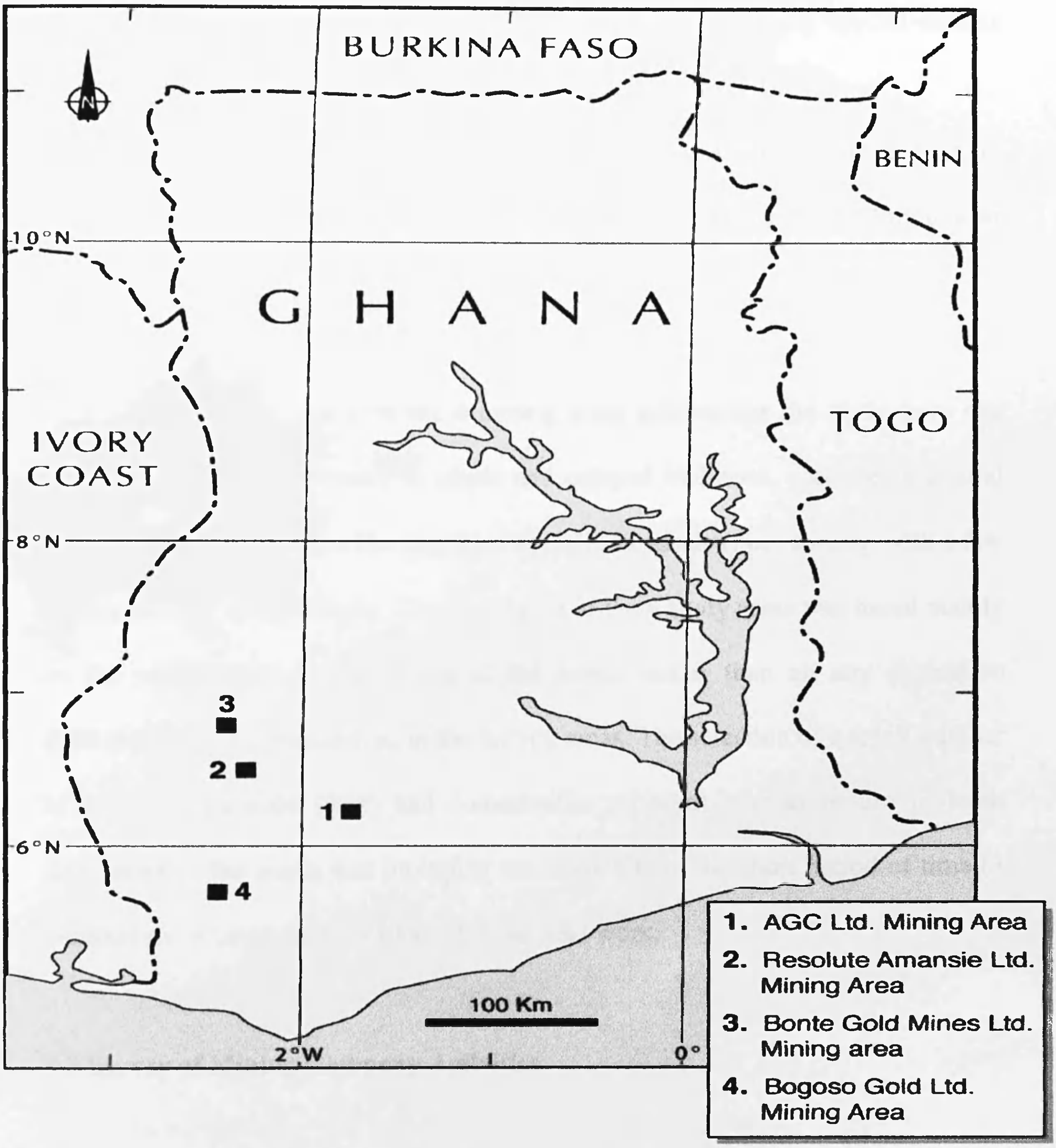

Figure 3.1: Map of Ghana showing the Study Sites

- Mining operations commencing after the promulgation of the Environmental Protection Agency Act 1994 (Act 490) – the Resolute Amansie Limited's gold mine in the Manso-Nkran area

- Mining operations in a river basin, with operations requiring special mining methods – the Bonte Gold Mines Limited's gold mine near Tetrem
- Mining operations in an environment relatively densely vegetated even after several years of mining activities – the Bogoso Gold Limited's gold mine near Bogoso

The sixteen communities from the 4 mining areas selected for the study have one thing in common: Uniformity in ethnic and cultural traditions, each being a rural community with majority of its members engaged in subsistence farming, with a few traders and few civil servants. Thus the choice of the 4 study areas was based mainly on the variations in key attributes of the mines, rather than on any distinctive differences in the communities, in the mining areas. The selection of a small number of mining companies (four) and communities (sixteen) was to ensure in-depth assessment of the issues that prompted the study within the short period of time (3 months) and limited funds available for the field work.

3.3 Survey of Mining Company Activities

Selection of mining areas for this study began with a discussion with the Ghana Chamber of Mines during which a list of all gold mining companies in Ghana and their annual gold production levels was obtained. From the annual gold production levels an area in southern Ghana where the bulk (> 70 %) of the gold in the country is produced, was selected. Further discussions were then held with senior staff of the Mines Department, and the Mining and Industry Department of the Environmental Protection Agency of Ghana to help select a representative sample consisting of four mining companies from the list of mining companies in the selected area in southern Ghana. In selecting the companies, cognisance was taken of such factors as scale of operations, nature of the mining environment and the type of mining method employed, all of which have been found to affect the nature and intensity of mining impacts (Down and Stocks, 1977). The mining companies finally selected were:

i. Ashanti Goldfields Company,

ii. Resolute Amansie Limited,

iii. Bonte Gold Mines Limited and

iv. Bogoso Gold Limited

3.3.1 *Ashanti Goldfields Company (AGC) Limited*

Among the factors upon which AGC's selection was based were the scale of its operations and its continuous engagement in mining activities in the Obuasi area spanning several generations. AGC has been operating in the Adansi West District of the Ashanti Region of Ghana since 1897. Its mine (Figure 3.2), which is located in the Obuasi area, has the reputation of being the oldest and largest mine in Ghana. Most of AGC's century-long operations were undertaken before the promulgation of the Environmental Protection Agency [EPA] Act 1994 (Act 490). This Act (section 12.1) mandates all mining companies whose operations cover more than 10 ha of land area to conduct an Environmental Impact Assessment (EIA), followed by the submission of an Environmental Impact Statement (EIS) to the EPA for evaluation prior to the commencement of mining operations. The Act also mandates companies

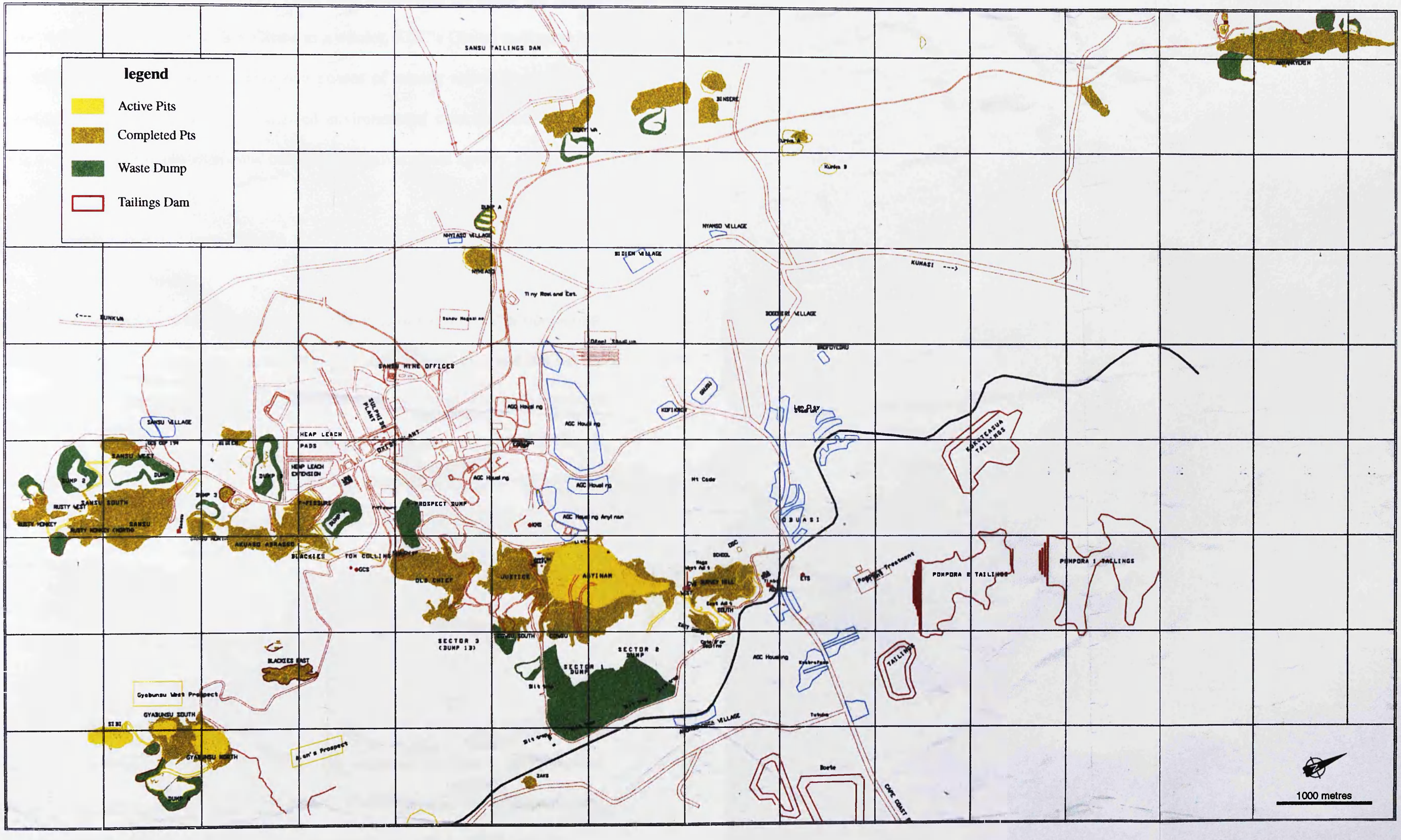

Figure 3.2: Mine Plan of Ashanti Goldfields Company (Ghana) Limited [AGC]

involved in large scale (> 10 ha) mining operations to submit to the EPA, an Environmental Management Programme (EMP) on all undertakings on their site that took place before 31 December 1994. Thus, apart from being the oldest and largest mine in the study area (and in fact, Ghana as a whole), AGC's Obuasi gold mine has the added research interest of having two phases of mining activities – activities preceding an era of use of clearly defined environmental controls, and activities within the era of strict environmental controls, by a government agency.

3.3.2 *Resolute Amansie Limited (RAL)*

Resolute Amansie Ltd (RAL) was selected on the basis of the scale of its operations, the relatively short period of its mining activities in the Nkran area and the era (in relation to the enforcement of the EPA Act 1994 [Act 490]) in which its activities began. RAL commenced operations at its Nkran mine (Figure 3.3) in 1996 (i.e., 2 years after the EPA Act 1994 [Act 490] came into force) after approval of its EIS by the EPA in 1995. Its operations cover an area of 5, 540 ha, just a fifth of AGC's area of operations.

3.3.3 *Bonte Gold Mines Limited (BGM)*

Bonte Gold Mines Limited's (BGM's) selection was based mainly on the location of its Tetrem gold mine (Figure 3.4) and the ore extraction method it employs. The mine is in the basin of two major rivers (Rivers Bonte and Jeni) – a site described by the EPA (Ghana) as an 'Environmentally Sensitive Area' (EPA, 1995).

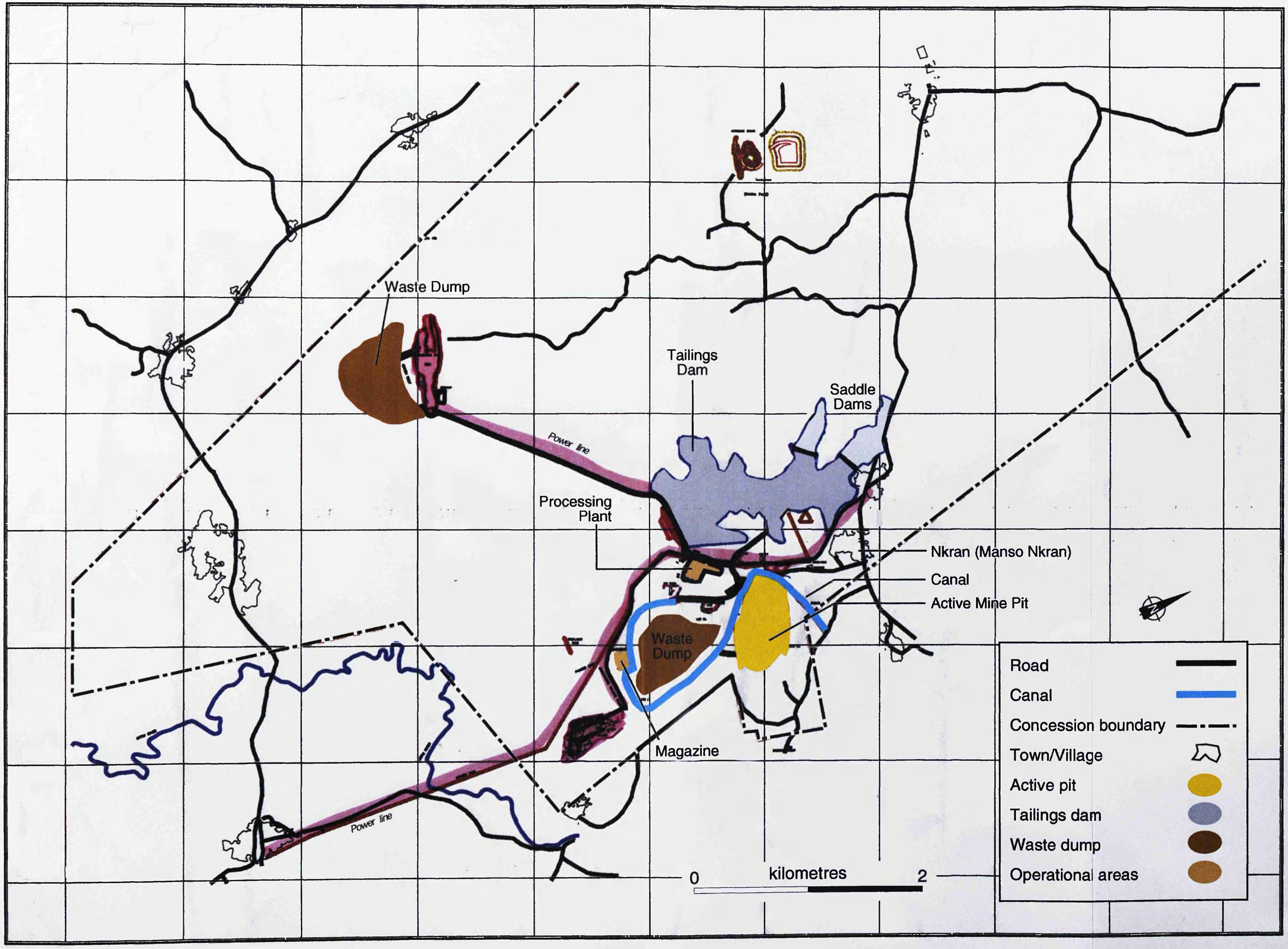

Figure 3.3: Mine Plan of Resolute Amansie Limited [RAL]

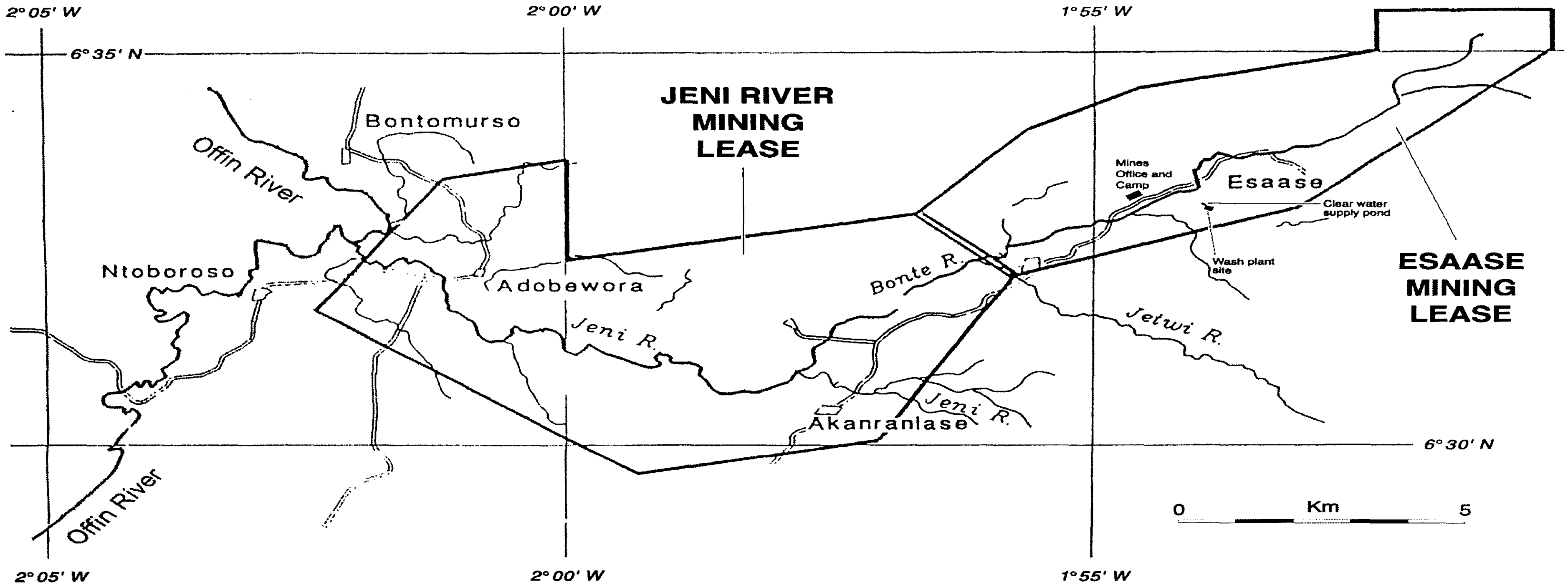

Figure 3.4: Mine Plan of Bonte Gold Mines Limited [BGM]

The total area of BGM's Tetrem mining concession is 6,500 ha, just a little larger than RAL's mining concession at Nkran. BGM commenced mining activities in the Tetrem area in 1991, 3 years before the Environmental Protection Agency Act 1994 (Act 490) was promulgated. Gold in the concession is extracted from alluvial ore deposits in the basin of the above-mentioned rivers, and hence, the ore extraction and processing methods employed are quite different from what is used for conventional surface mining operations (especially those carried out in relatively dry environments).

3.3.4 ***Bogoso Gold Limited (BGL)***

The Bogoso Gold Limitd's (BGL's) gold mine in the Bogoso area (Figure 3.5) was selected mainly due to the sharp contrast in vegetal cover between the mining area (relatively densely vegetated) and most of the mining areas in the study area (with very sparse vegetal cover), despite the many similarities (such as the number of years of mining operations, scale of operations and the mineral extraction method) that it shares with most of the mines in the study area. It was therefore of research interest to find out whether specific factors, especially environmental management measures put in place there, were responsible for this phenomenon. BGL commenced gold mining activities in the Bogoso area in 1990; 4 years before the EPA made it mandatory for proponents of large-scale mining operations to conduct EIA of their operations before commencing mining activities. BGL's mining concession near Bogoso covers an area of 9,800 ha.

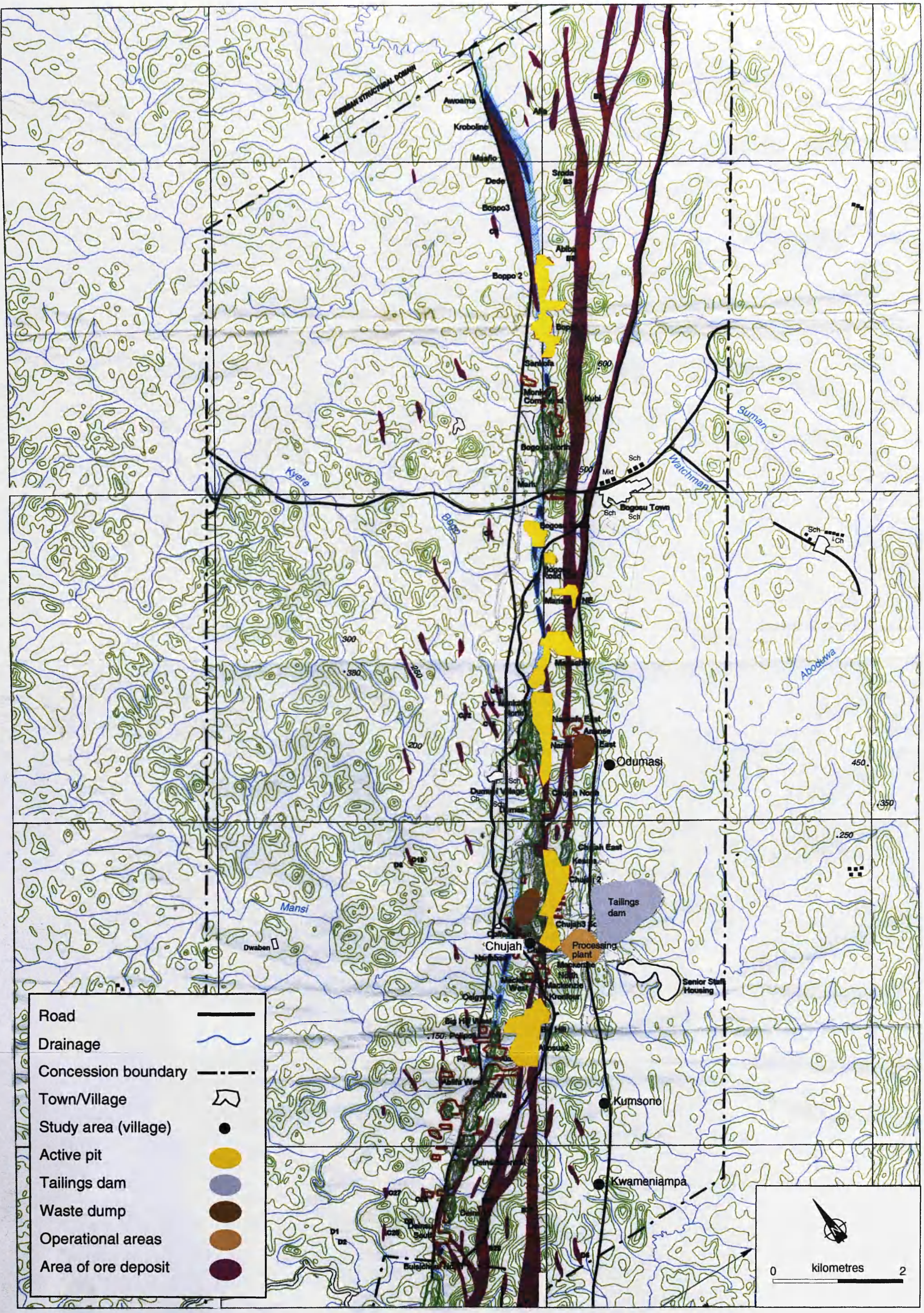

Figure 3.5: Map showing BGL's Mine Plan, and Location of Selected Communities in the BGL Mining Area

3.4. Survey of Rural Communities: Population Sampling Method / Selection of Sample Groups

With the exception of the AGC mining area where two villages close to the company's mine site near Obuasi, and two other villages near their Sansu mine site were selected, in all the mining areas the selection of the study villages was as follows:

For each mine, starting from the village closest to the mine and moving away from the mine along the main road linking the villages in the mining area, the first 3 villages encountered, together with the village closest to the mine, were selected. Using this approach, the villages shown in Table 3.1 and Figures 3.5 – 3.8 were selected in the various mining areas. Thus, in each mining area, four villages close to each mine were selected for a study to ascertain the impacts of mining activities on the inhabitants of the villages.

Ideally, several villages ranging from those as close to each mine as possible to those as far away from the mines as possible should have been selected for a study of this nature. However, due to the fact that the educational status of most of the community members necessitated the use of elaborate personal interviews in the local dialect of the communities in the study area using well-structured questionnaires, coupled with the limited time and funds available for the field survey, only a few (four) villages were eventually selected in each mining area, for

Table 3.1: Villages selected for the Community Surveys and their Distances from the Respective Mines

Area	Village	Distance from Mine (km)
AGC MiningArea	Sansu	4.30
	Aduaneyede	4.50
	Ahansonyewodea	5.00
	Ampunyasi	15.0
RAL Minig Area	Manso-Nkran	0.90
	Koninase	1.50
	Dadease	1.60
	Kaniago	2.90
BGM Mining Area	Tetrem	0.50
	Bonteso	2.90
	Mpatuom	5.70
	Jeniso	7.20
BGL Mining Area	Chujah	0.03
	Odumasi	0.25
	Kumsono	2.50
	Kwameniampa	3.60

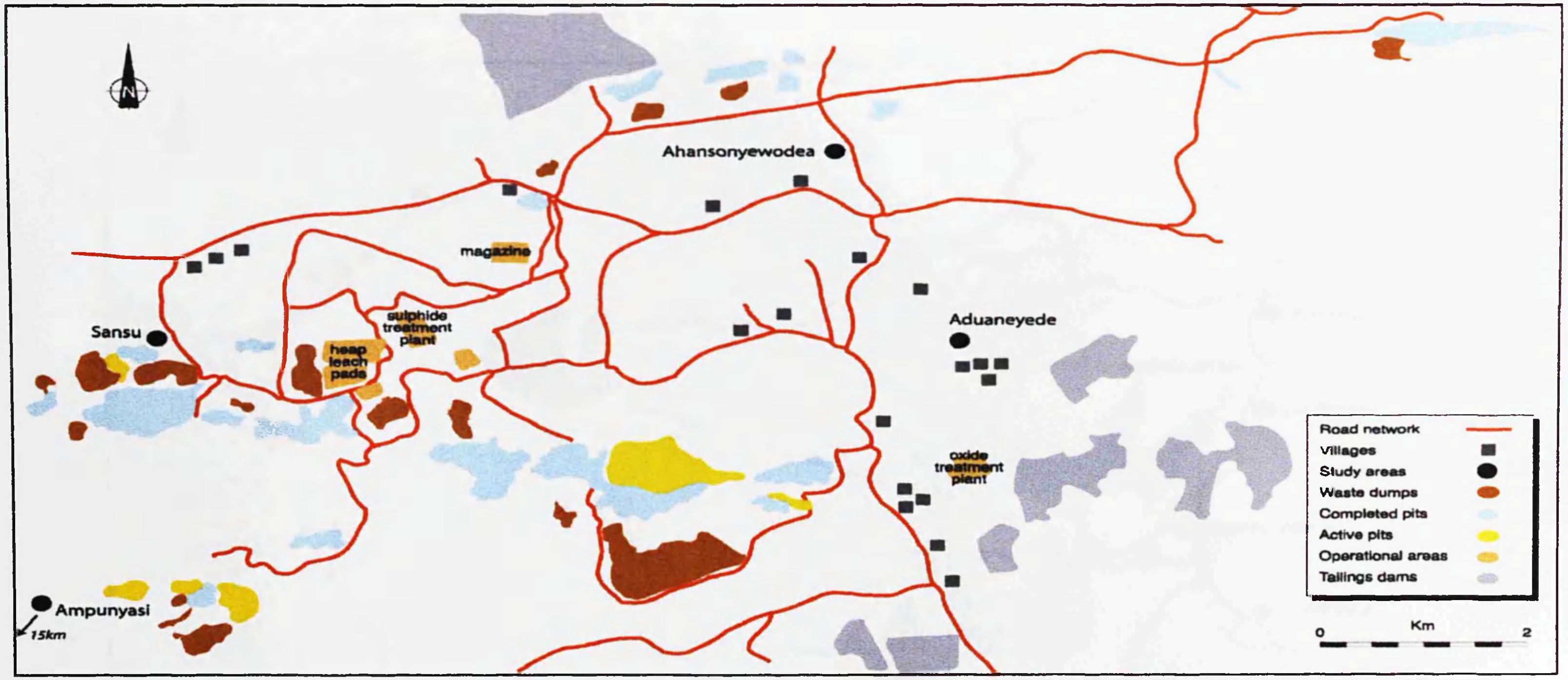

Figure 3.6: Map showing Location of Selected Communities in the AGC Mining Area (Derived from Ghana Topographical Map (Sheet) No. 0602C1 and AGC's Mine Plan

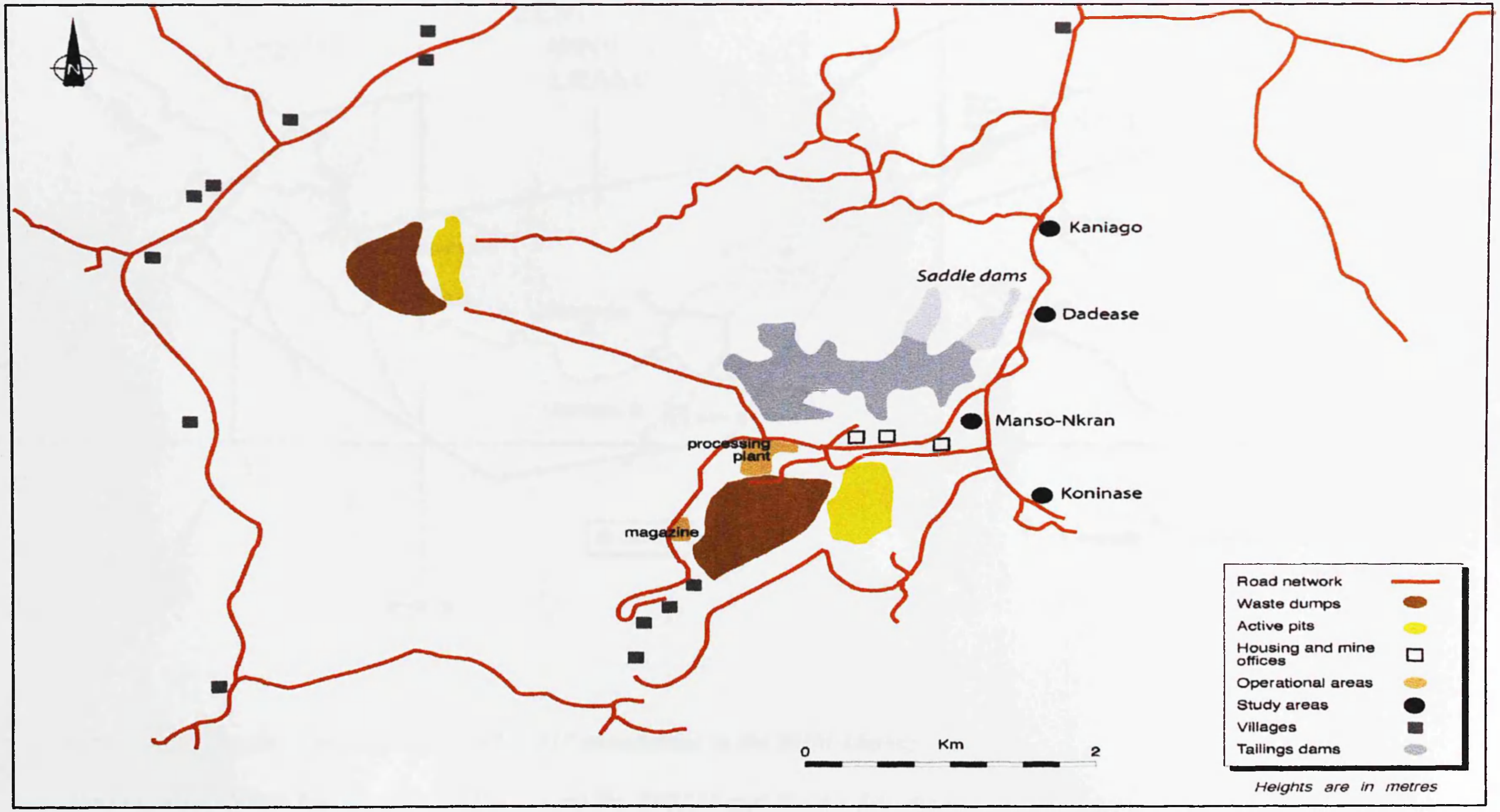

Figure 3.7: Map showing Location of Selected Communities in the RAL Mining Area

(Derived from Ghana Topographical Map (Sheet) No.0603D2 and RAL's Mine Plan)

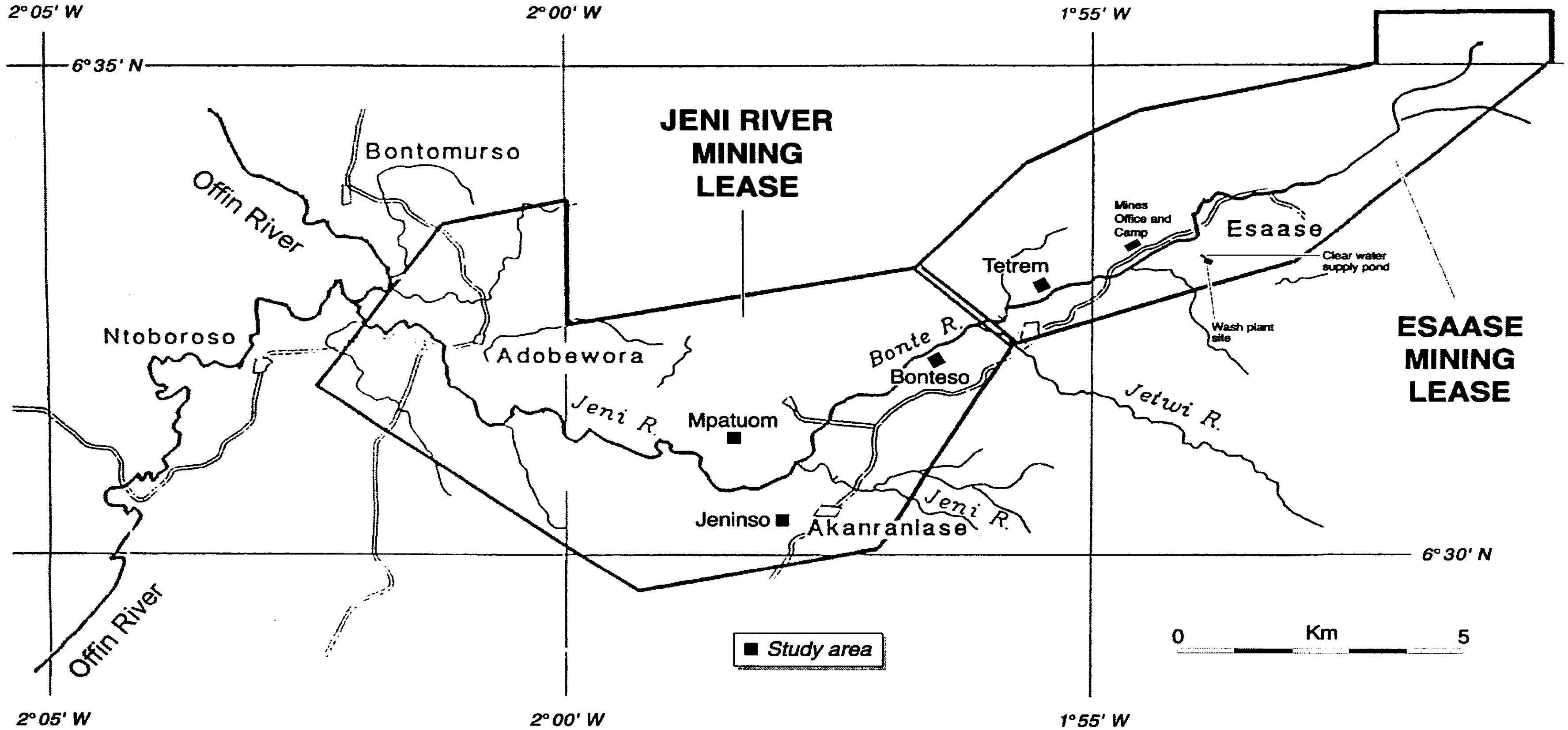

Figure 3.8: Map showing Location of Selected Communities in the BGM Mining Area

(Derived from Ghana Topographical Map (Sheet) No. 0602A3 and BGM's Site Plan

the study. And since one of the key objectives of the study was to assess the environmental and socio-economic impacts of surface mining in southern Ghana and the effectiveness of environmental management measures put in place by the mining companies operating there to minimise adverse impacts of their operations, the study was limited to villages as close to the mines as possible.

In each of the sixteen selected villages, a random sample of 20 adults from the 'General Community' were interviewed (twenty adults aged 20 and above, from 20 randomly selected households agreeing to be interviewed, irrespective of their gender). Again, using the multiple-staged sampling technique (Moore & Cobby, 1998), 10 farmers and 10 housewives, together with 5 fishermen and 5 hunters identified through the Development Committee (officially called the 'Unit Committee') of the village were earmarked for questionnaire-based interviews. Thus in all (16 communities), 800 people were eventually interviewed. Apart from the two small groups (fishermen and hunters) whose members had to be specifically identified (due to the fact that very few of them were still engaged in active fishing or hunting at the time of the survey), the selection of the various groups eventually interviewed was based on the method used by Krannich and Smith (1998), and the multi-stage sampling technique (Moore & Cobby, 1998), as follows:

3.4.1 *General Community*

In each village, a simple random sample of 20 households was selected. A randomly selected adult (aged 20 or older) resident of each selected household was then interviewed by asking them questions from a questionnaire (Appendix 18) and using their responses to personally complete the questionnaire.

3.4.2 ***Farmers and Housewives***

At each village, a meeting was first held with the Unit Committee (a constitutionally established committee that liaises between each local community and the District Assembly on community development issues). With the help of the Committee, two lists, one, of adult farmers and the other, of housewives, were compiled from the Committee's copy of an updated version of the 1996 electoral register that was to be used for the 2000 general elections. 10 farmers and 10 housewives were then randomly selected from the two lists for interviewing using questionnaires specifically designed for farmers (Appendix 19) and housewives (Appendix 22).

The nature of the information required necessitated some bias in this particular study. For instance, adults (aged 20 and above) had to be used to ensure that most of the selected respondents were mature enough to be familiar with the history of mining in their respective communities. Again the fact that among the 'Akans' (the natives of the study area), it is women (not men) who are responsible for firewood fetching, purchase, etc., while fishing and hunting are solely the preserve of males meant that only females (housewives in this case) could be targeted in trying to obtain information pertaining to surface mining impact on firewood accessibility or availability. Again, only males could be targeted, in the case of data on mining impacts on fish and game abundance. In fact, there have been similar environmental studies in the past that necessitated such bias towards age (Feijoó and Momo, 1991; Burger and Sanchez, 1999) and gender (Burger and Sanchez, 1999).

3.5 **Preliminary Questionnaire Design / Pilot Study**

The design of questionnaires for both the mining company and rural community data collection was based on Gilbert's (1993) method of producing effective questionnaires for field surveys. Among other things, the mining company questionnaire was designed to help ascertain the types of environmental management programmes pursued by the mining companies in the study area and the effectiveness of the programmes in the minimisation of adverse environmental and socio-economic impacts associated with the companies' operations. Questions posed thus sought information on various aspects of the mine and mining process including the location and site characteristics of the mines, number of years of mining operations, area of the mining concession, methods, techniques, chemicals, etc., employed at the various phases of the mining cycle, as well as environmental management and monitoring programmes put in place at the mines and their effectiveness in providing solutions to adverse mining impacts.

A pilot study aimed at finding out how effective the questionnaire was in helping to obtain the above data was carried out at the AGC mining area. The pilot study was also to help improve, if necessary, the wording and conciseness of the questions and instructions. AGC's Environmental Manager was made aware of the objectives of the study and the fact that AGC was one of four companies in southern Ghana selected for the study. The purpose of the pilot study was explained to him. The questionnaire was then given to him for a week, having been given the leeway to make as many changes, suggestions and comments as necessary, in addition to completing the questionnaire. Around the same time, a copy of the questionnaire was given to a Deputy Chief Inspector of Mines in charge of the Western Region to study it and make necessary suggestions and comments. The choice of AGC for the pilot study was largely based on an earlier rapport that had been established with the company's experienced environmental manager which was likely to help speed up a data collection process involving companies (mining companies in Ghana) who, more often than not, are reluctant to make information that includes mining environmental impacts available to researchers. Similarly, the choice of the Western Region Mines Department Manager to study and comment on the effectiveness and appropriateness of the questionnaire was based on the fact that apart from being an experienced Mining Engineer with a Postgraduate Degree in Environmental Management who had been involved in monitoring of mining activities (including environmental management programmes) at the mines in the Western Region of Ghana, he was one of few colleagues I had discussed the research with at its very early stages, and who had shown enthusiasm for the study. He was therefore likely to attach seriousness to the exercise once tasked with it.

At the end of the week, separate meetings were held with the two officers for discussions on the questionnaire. After a careful study of the AGC-completed questionnaire and suggestions and comments made by the Environmental Manager and the Deputy Chief Inspector of Mines, the questionnaire for the mining company data collection was revised and a final one produced. For instance, a question asking the companies about the existence and current status of 'abandoned mined sites' within their concessions had to be deleted from the questionnaire. This was because during the pilot study, it was revealed that there was hardly any 'abandoned mined site' in most of the mining concessions in Ghana, unless a company had completely wound up operations and moved away from a site with no intention of returning there – that with improvement in technology, there has always been the tendency for companies to go back to previously mined areas within their concession to attempt to mine if it is discovered new technology and mining techniques will enable them obtain profits from such a venture. It was however disclosed that there were some unmined sites without economic ore deposits within the concessions that had been degraded as a result of past mining activities. Thus the questionnaire had to be revised to enable the mining companies to respond to questions on 'degraded' sites within their concessions, instead of 'abandoned mined sites' as depicted in the original questionnaire.

Each of the questionnaires for the community surveys was designed with the particular characteristics of each group and the likely impact of mining activities on the socio-economic lives of group members in mind. Thus the questionnaire for the general community which was directed to adult members of the communities irrespective of their occupation featured questions that requested for respondents' occupation, age and origin. In the original questionnaire, they were also, *inter alia*, asked to rank mining-related problems they were confronted with in order of acuteness. Again, they were asked to rank the positive impacts that mining had on their respective communities in a similar way. They were also asked to rank what they wished the mining companies could do to reduce adverse mining impacts on their communities in order of priority.

In addition to some of the above general questions, the questionnaire for the farmers included questions that sought to find out about how mining activities affected their crop production levels, the percentage of their farm destroyed through mining activities and whether they were satisfied with compensations they had been given after losing farms, farmlands, etc., to mining activities. The questionnaire that targeted fishermen included questions that specifically asked about fish-catch trends over the years and the main impacts of surface mining on fishing and fishery resources in the mining areas. The questionnaire for the hunters was also designed to among other things, seek information on the trends in animal kill, trapping, etc., over the years and the impact mining activities had on animal populations in the mining areas. In the questionnaire designed for housewives in the study area, respondents were among other questions, asked to state average distances covered to reach sources of their household firewood over the years and what factors they perceived were responsible for changes, if any, in distances covered from year to year.

The questionnaires were pre-tested on small samples in the Sansu and Ampunyasi communities in the AGC mining area and the Chujah and Kwameniampa communities in the BGL mining area. The two villages selected in each mining area were those closest to (Sansu and Chujah) and furthest from (Ampunyasi and Kwameniampa) the mines in the respective mining areas. Just as in the case of the mining company questionnaire, the community pilot surveys were to help improve the wording, conciseness and usefulness of the community questionnaires. In each of the chosen villages in the 2 mining areas, random samples of 10 members of the general community, 5 farmers and 5 housewives were personally interviewed together with 3 each of identified fishermen and hunters. The pre-testing of the community questionnaires in the two mining areas above was just to help save time. Since the first two villages (Sansu and Ampunyasi) are located in the AGC mining area where the mining company questionnaire was pre-tested and the remaining villages (Chujah and Kwameniampa) are close to Tarkwa where the office of the Deputy Inspector of Mines who was asked to help reshape the mining company questionnaire was located, it was possible to undertake both tasks (the questionnaire-revision process for both the mining company and community questionnaires) around the same visiting time.

During the community pilot study, it became increasingly obvious that there was the need to re-design or revise portions of the questionnaires. For instance, although all the questionnaires for the community surveys had originally been designed in accordance with the format recommended by Newton and Rudeston (1999) in which suggested responses to questions are coded and made to be ranked by interviewees to allow for comprehensive analysis of the data eventually collected, this format had to be abandoned in favour of a more flexible approach. This was due to the difficulty encountered – while pre-testing the questionnaires – in having the rural communities rank mining impacts and other issues of interest in order of magnitude, priority, etc. Thus a system that involved the listing of a specified number of remarkable or top-ranking impacts had to be devised. A typical example was a question in the questionnaire for the general community that asked for the ranking of adverse mining impacts on respondents' communities on a scale of 1–5 representing 'Negligible Impact' (1 on the scale) through to 'Very Serious Impact'

(5 on the scale) from a list of 7 typical impacts, where almost all the respondents ranked every listed impact '1' on the scale to portray the severity of each of the negative mining impacts listed. This, obviously, was going to make the eventual results of the study rather unrealistic. And the fact that it was taking an awful lot of time trying to 'school' each of the respondents into adequately understanding the dynamics of the ranking process and more importantly, the purpose of ranking the issues, suggested that given the time and resources available for the field survey, one of two options had to be resorted to: 1. Abandoning the community surveys and using only the information that was going to be provided by the mining companies in the study of the mining impacts or 2. Devising an alternative means for soliciting information that would at least, represent to a reasonable measure, the perception of the rural communities of mining impacts on their environment and socio-economic lives. The later option was finally settled on – respondents were asked to list a specified number of mining-related adverse or beneficial impacts, with an option to choose from a list of suggested impacts. For example, instead of asking them to rank the adverse impacts referred to above in order of acuteness, they were simply asked to list up to 5 impacts they considered the most worrying.

3.6. **Design of Final Questionnaire**

3.6.1 ***Questionnaire for Mining Company Data Collection***

The final questionnaire for the mining company data collection (Appendix 17) was designed after a careful study of the suggestions and comments following pre-testing of the questionnaire. In Questions 1 – 4 of the final questionnaire, each of the selected companies was asked to supply information on location of the company (Q1), the number of years the company has been operating in the mining area being studied (Q2), the area of mining concession (Q3) and the area of the concession occupied by current mining operations (Q4). These questions were to help have some idea about the size of operations, geographical and locational attributes of the mine site, all of which are known to have a bearing on the nature and extent of mining environmental impacts (Down and Stocks, 1977). To be able to assess the environmental controls in the Ghanaian mining sector and the role they play in the mitigation of adverse mining impacts, Question 7 requested the companies to outline all statutory requirements that had to be fulfilled prior to commencement of mining operations. Questions 8 and 9 were then set to find out the types of, and techniques used in collecting, baseline studies prior to the constructional and operational phases of the mining project. These questions were to help find whether proven techniques were used and whether a link could eventually be established between the effectiveness, absence, etc., of baseline studies and the seriousness of environmental problems created at the various mines.

The importance of 'Planning and Design' to the mitigation of adverse mining impacts (Down and Stocks, 1977) had been taken note of in the design of the mining company questionnaire. Thus Question 9 which dealt with baseline studies was closely followed by a question (Question 10) that asked the companies to indicate how results of the baseline studies, if carried out, were applied in the 'Planning and Design' of various aspects of the mining process (exploration / prospecting, bulk sampling, site preparation, location of mine site facilities, etc.) to minimise adverse impacts of mining activities. Questions 11 and 12 then asked the companies to state the main beneficial (Q11) and negative (Q12) impacts of their mining operations. Then, bearing in mind that environmental and socio-economic impacts created by mining activities (addressed by Question 12) could be greatly minimised through the use of appropriate techniques / technologies at the various phases of the mining cycle (Foray and Grubbler, 1996; Warhurst and Bridge, 1996), Question 13 requested the companies to give details of specific techniques / technologies employed to minimise adverse environmental and socio-economic impacts of their operations. Based on findings of past studies that the chemistry (Kelly, 1988) and geochemistry (Thorton, 1975) of the mining environment together with the chemicals and reagents used at the various stages of the mining process (Broman, 1990) are a great determinant of the nature of the pollution problems that could be created during, and in many cases even after cessation of, mining operations, Questions 14, 15 and 16 were posed to help get a fair picture of the environmental pollution problems that should be expected at each mine if adequate pollution prevention and control measures were not put in place. The questions were also to help find out specific environmental management mechanisms put in place at the various mines to minimise pollution problems. In Question 14, the companies were asked to tick any chemically active materials that accompany gold mineralisation in their respective mining concessions from a list of well-known materials (pyrites, arsenopyrites, diorites, etc.). Question 15 then asked them to state the nature of the ore deposits – whether they are clayey, sandy, gravelly, etc.

The companies were to respond to Question 16 by completing a 3-column table with the headings i. 'Operations / Processes', ii. 'Chemicals and Reagents' and iii.

'Mitigation Measures'. This was to be used to obtain information on the types of chemicals and reagents used at the various stages of the mining process and the environmental management measures employed by the companies to minimise adverse impacts associated with the use of these chemicals and reagents. The issue of specific steps taken by the companies to minimise air-, land- and water pollution problems at the various mines was addressed by Question 17, which requested the companies to complete a table detailing mitigation measures employed to tackle various pollution problems at the mines (Q17 a) and a table requesting for information on the types of pollutants produced, their average concentrations before being discharged into the environment, and the nature of the receiving medium (Q17 b). Sections of Question 17 among other things, requested the companies to provide information on specific environmental regulations and standards that govern the disposal of wastes generated by their operations (Q17 c), the handling of tailings and other wastes (Q17 d – 17 i) from mining operations. The remaining information on environmental management measures put in place at the mines were solicited by Questions 18 – 21 which requested the companies to give information on their Environmental Policy and Policy Objectives (Q18), Execution of Environmental Management Programmes (Q19), Current Environmental Monitoring Programmes (Q20), Rehabilitation, Reclamation and Restoration Programmes (Q21) and Monitoring Programmes intended to be put in place after cessation of mining operations (Q22).

All the information above that the questionnaire was to be used to obtain were to help appreciate the type and scale of mining impacts at the various mines and in the eventual assessment of the effectiveness of the environmental management programmes operated by the mining companies to mitigate adverse mining impacts.

3.6.2 ***Questionnaires for Community Surveys***

The five sets of questionnaires for the community surveys were finalised (after pre-testing their original versions) as follows:

3.6.2.1 *Questionnaire for the General Community*

The questionnaire for data collection from the general community consisted of 10 open-ended and closed questions (Appendix 18). The first 5 questions were to help identify the Occupation (Q1), Age (Q2), Sex (Q3) and Origin (Q4) of respondents as well as the number of years they had been living in their respective communities (Q5), all of which are known to affect people's perception of environmental effects of projects to some extent (Feijoó and Momo, 1991). Question 6 then asked respondents to list up to 5 positive mining impacts on their respective communities that they considered most remarkable. This was followed by a question (Q7) that asked for the listing of up to 5 most serious negative mining impacts that they were aware of. A question (Q8) requiring them to briefly explain the nature of the problems they considered to be of most concern to their respective communities was then posed. Question 9 asked respondents to specify any measures they were aware, were being undertaken by the mining companies in their communities to mitigate the adverse mining impacts previously listed in response to Q7. The last question (Q10) then asked respondents to indicate five solution measures they felt would be most beneficial to their communities, with the option to choose from a list of suggested measures. The last two questions above (Q9 and Q10) were posed to help ascertain whether environmental management programmes at the mines had been designed with the needs and aspirations of the local communities in mind.

3.6.2.2 *Questionnaire for Farmers, Fishermen, Hunters and Housewives*

Questions 1 and 2 were the same for each of the remaining groups (farmers, fishermen, hunters and housewives). While Q1 requested for information on how long respondents had been living in their respective communities which was to be chosen from a list of 5 age brackets, Question 2 requested respondents to indicate how long they had been involved in a particular activity (fishing, farming, etc.). The remaining questions differed from group to group. The farmers' questionnaire had questions that requested for information on the types of crops produced (Q3) and the level of adverse mining impact (whether High, Low, etc.,) on crop production levels over the years (Q4). Question 5 of the farmers' questionnaire asked them to explain the nature of the mining impact on their crop production levels.

Questions 3 – 5 of the questionnaires for the fishermen and hunters requested for information on their current level of involvement in fishing or hunting activities (Q3), the trend in fish or game numbers over the years (Q4) and the perception of the respondents of the causes of the trend in fish or game numbers over the years. The above questions were asked to help assess any possible links between mining activities and the 'status' of fishing and hunting activities.

In addition to the two questions that were general to all the four groups above, the questions for housewives in the study area were framed to solicit information on the types of fuel normally used by respondents for cooking (firewood, charcoal, gas, etc.) (Q3). Question 4 of their questionnaire asked users of firewood among respondents to state how their household firewood was obtained (whether purchased or fetched from the bush). Question 5 was directed to respondents found to fetch their household firewood from the bush, asking them to state the average distances they had been covering over the years (' 5-10 years ago', 1-5 years ago and 'Currently') to reach their source of firewood. The last question (Q6) of the housewives' questionnaire asked respondents to state what they perceived to be responsible for the trend in firewood accessibility in their respective communities over the years. This would assist in analysis of possible relationships between mining activities and firewood availability and accessibility in the various communities.

3.6.2.3 *Reflection on Social Survey in Study Area / Humid Tropics*

The fact that it was not possible to use conventional (ranking) techniques to ascertain the magnitude of mining impacts as perceived by communities in the study area means it would be inappropriate to compare the results of the community surveys with results of future research in the region. Another limitation of this research is that it was not possible to carry out community surveys at 'control' sites (including villages far away from the studied mines) as explained in paragraph 3 of section 3.4. This obviously makes it difficult to draw the kind of unequivocally convincing conclusions usually drawn at the end of most scientific investigations with one or several 'control' sites. However, it must be pointed out that the social survey questionnaires used in this study were prepared with *mining area communities* in mind, and the questions were set to help ascertain the impacts of gold mining on these communities. Therefore to carry out surveys at 'control sites' (e.g. sites without any mining activities), different sets of questionnaires would have had to be designed and used. However, in future, similar research in the study area should not only look at the effects of large-scale mining on community natural resources but also, the impact of other factors that can adversely affect these resources. The need for this stems from the likelihood that problems caused by factors other than those listed / outlined by respondents as being caused by large scale mining close to their communities, may also have contributed to the identified problems. Some of the possible factors are outlined below:

i. *Effect of Licensed (Legal) and Unlicensed (Illegal) Small Scale Mining Activities*

As explained in Section 1.1.4 of Chapter 1 (Page 17, Paragraph 3 to Page 19, Paragraph 2), small-scale gold mining activities (including illegal operations) are carried out in many parts of Ghana. In this section also, the environmental problems caused by small-scale mining operations in the country are outlined.

The mode of operation of small-scale miners in Ghana – such as operating close to or within large-scale mineral concessions either legally or illegally and the use of sluicing / panning and amalgamation techniques for ore processing – is similar to that employed in many other developing countries such as Zimbabwe (Maponga & Ngorima, 2003), Chile (Castro & Sánchez, 2003) and India (Ghose, 2003). Similar approaches are used by small-scale miners in Papua New Guinea (Crispin, 2003) and Ecuador (Tarras-Wahlberg, 2002).

Both licensed and unlicensed / illegal small-scale mining activities have some negative impacts on the environment (Aryee *et al.*, 2003). These impacts have been comprehensively described by several authors (including Aryee *et al.*, 2003; Maponga & Ngorima, 2003; Babut *et al.*, 2003; Hilson, 2002a; Castro & Sánchez 2003; Ghose, 2003; and Hilson, 2002b). In Zimbabwe where the effects of small-scale gold mining activities have been extensively studied, it has been reported (Maponga & Ngorima, 2003) that in addition to the destruction of vast tracts of forests, panners move an estimated 8 million tonnes of material annually and in the process, destroy significant portions of riverbanks. The panned waste also chokes river channels, resulting in flooding during the rainy season (Maponga & Ngorima, 2003). In the Portovelo-Zaruma area of southern Ecuador where artisanal small-scale gold mining is prevalent, Tarras-Wahlberg (2002) has reported that the mining and processing methods involved have caused a variety of environmental problems including deforestation and increased erosion. This author has also attributed the absence of fish and invertebrates in one river in the area (River Calera) and reduced faunal population in another river (River Amarillo) to pollution from tailings produced from small-scale gold mining activities upstream. Castro and Sánchez (2003) have identified pollution by liquid effluents discharged to rivers, and contamination of surface and underground waters by solid waste and processing chemicals as the principal environmental impacts of the Chilean small-scale mining sector. Ghose (2003) also reports of deforestation, accompanied by accelerated soil erosion and landslides, and turbidity in rivers and streams resulting from small-scale mining activities in the Indian Himalayas region.

One of the most serious problems associated with small-scale mining operations is pollution from mercury used in the amalgamation process. In fact, in many third world countries, mercury has become a major environmental problem in small-scale gold mining regions due to its extensive use in these regions. For instance, some 60 percent of small-scale miners in Papua New Guinea use mercury for gold processing (Crispin, 2003). In Zimbabwe, an estimated 6 tonnes of mercury is used annually by illegal small-scale miners. However, about 50 percent of the mercury (3 tonnes) is lost on amalgam plates and barrels, and to the atmosphere during retorting, causing water quality problems, with serious consequences for aquatic fauna and flora (Maponga & Ngorima, 2003). Mercury is insoluble and thus persists within river sediments, from where it is transported throughout the food chain, eventually reaching humans (Crispin, 2003). The use of mercury in small-scale gold mining operations has been known to have serious environmental impacts (Hilson & Murck, 2000). For instance, mercury pollution has caused irreversible damages to vast, potentially productive regions of the Brazillian Amazon (Pedlowski *et al.*, 1997). In a study on the environmental impacts of small-scale gold mining activities in a mining village in southern Ghana (Babul *et al.*, 2003), sediment samples analysed were found to be significantly contaminated with mercury, while fish filets (60 percent of sampled fish) had mercury contents exceeding the United States Food and Drugs Agency (US-FDA) action level, and therefore considered unfit for human consumption. These researchers attributed the problem to the amalgamation process used for gold processing by small-scale gold miners in the area.

From the above discourse, it is clear that there is the possibility that mining-related environmental and socio-economic impacts in the study area could have been exacerbated by small-scale mining operations, some of which might be unknown to local authorities interviewed in this study. Therefore ideally, in studying community perceptions of the impacts of large-scale mining activities in the study area, it would have been useful if other mining area communities outside the reference (study) area were also studied. Three different sets of communities could have been studied as follows:

- Communities in areas with only large-scale mining operations
- Communities in large-scale mining areas known to have pockets of small-scale mining operations
- Communities in areas with only small-scale mining operations

However, with respect to the last category, survey would need to be extended to areas distant from large-scale mines.

Even with the above-suggested approach, it may not be easy to identify / select such study areas with 100 percent confidence, given that a significant number of small-scale miners in Ghana operate illegally (Aryee *et al.*, 2003). As pointed out by Hilson (2002a), although a great number of mining companies in Ghana have legally obtained plots of land from the Ghanaian Minerals Commission, management has often discovered, following periods of prospecting, that small-scale miners are operating illegally within the same concession. A number of large-scale mining companies in Ghana after acquiring prospecting licenses, have been unable to prospect for some time due to financial constraints or other technical hitches. In such instances, the concessions are left at the mercy of illegal miners, since no security measures are put in place to prevent encroachment. Even on concessions that are being actively mined by large-scale operators, areas not being immediately worked have been known to be under siege by illegal small-scale miners (Aryee *et al.*, 2003). It therefore goes without saying that even with the suggested sampling method above, the results of the study may not necessarily reflect the 'true picture' on the ground. To overcome this problem, knowledge of the existence or otherwise, of illegal mining operations should be carefully sought from local communities. For instance, once they are convinced that the research is purely an academic exercise not intended to 'expose' illegal miners in their communities, many community members would be prepared to give valuable information and offer necessary help. In fact, they have adequate knowledge about what is happening in their local forests and landscapes, which can be tapped by the researcher.

ii. *Effect of Population Pressure / Anthropogenic Activities*

Mining operations, because they tend to be located in rural areas, commonly induce major changes in local demographics, precipitating migration from neighbouring villages and townships. A large percentage of those that migrate are redundant mine labourers from other areas trying to secure employment at the mine, and small-scale mining entrepreneurs seeking to exploit portions of the ore body being worked

(Hilson, 2002b). In Ghana, there has been a general influx of migrants from the Northern, Upper-East and Upper-West Regions to the Brong-Ahafo, Ashanti and Western Regions of the country over the years, to take advantage of the fertile lands and job opportunities available here. In the Western and Ashanti Regions in particular, a lot of people from the northern and other parts of Ghana have moved and settled there due to the fertile soils, mining and timber industries and associated enhanced farming, trading and employment opportunities in these two regions. Dickson and Benneh (1988) for instance, have attributed the sharp increase in population in the two regions to the many mining and timber industries there, a source of employment to people from many parts of the country.

Ghana's population, which has been increasing at a rate of 2.3 percent annually (World Bank, 2001), stood at 18.9 million in 2000 (Ghana Statistical Services, 2001). Many cities are expanding and vast expanses of rural land – already finite in supply – are disappearing as a result of human encroachment (Hilson, 2002a). Rural-urban migration is widespread in developing countries. In the Ashanti Region of Ghana, where urban communities pre-date 19th Century colonial impacts, the growth and demands for food and fuel for towns such as Kumasi, Mampong and Bekwai have placed increasing pressure on forest resources and farmlands. The impacts of mining towns, such as Obuasi, exacerbate this general trend. Even in the absence of 'environmentally unsustainable' activities like mining, problems such as deforestation and water pollution may occur as a result of population pressure. In Zimbabwe, it has been reported (Maponga & Ngorima, 2003) that increased population density in small-scale mining villages has resulted in accelerated timber harvesting for construction purposes and for use as fuel.

Personal experience / knowledge regarding the extent of deforestation, land degradation and loss in water quality in some densely populated areas in the Brong-Ahafo Region of Ghana where mineral exploitation activities have never been undertaken, suggests that population pressure and associated increased anthropogenic activities can exert enormous pressure on natural resources.

It is clear from the above trends and observations that the methodology for measuring mining impacts on the environment needs to be developed to separate out the major factors affecting environmental degradation. These are notably:

- Population growth
- Increased commercialisation of rural economy
- Poverty
- Direct and indirect impacts of mining

iii. *Community Level of 'Ecological' Knowledge and Effect on Impact Perception*

The community surveys revealed that community members' knowledge of environmental issues and their literacy levels may have some impact on their perception of the environmental and other impacts of industrial activities in their communities. Purnama (2003) has indicated that low-level education and a lack of environmental awareness of the general public are major constraints for effective public involvement in the EIA process in Indonesia. Lack of environmental awareness is a serious issue in Ghana especially, among the rural population. Most villagers in Ghana cannot read (Appiah-Opoku, 2001). In a 2000 'Ghana Labour

Survey', it was ascertained that 33 percent of all adults – representing 6 million of a total population of 8.9 million – had never been to school (Ghana Statistical Service, 2001). The high illiteracy levels in rural Ghana make it necessary for appropriate strategies to be used when soliciting information from rural communities in the country. The use of focus group discussions during the community surveys in this study proved a very useful information-gathering strategy in the rural communities studied. Appiah-Opoku's (2001) suggestion that consultations during EIA studies in rural Ghana should take the form of roundtable discussions in the communities' own language and style, supported with pictures and graphics that describe complex issues, is indeed laudable. According to Jarvis and Younger (2000), in mine water environmental impact assessment studies, while ranked lists undoubtedly serve as useful yardsticks of pollution severity, it is important to supplement these technical data with local information. They further suggest that during such studies, information such as proximity to residential areas, impact on amenity value as well as actual and potential impacts on water abstraction and / or supply should be gathered, even if knitting this information into a semiquantitative format is not possible in the short term.

The use of a 'hybrid' approach to studies on sustainable development – in which scientific and indigenous knowledge about environmental degradation are combined – is argued to be more accurate in assessing human experience of environmental problems. This approach can also help in giving insight into the power relations between indigenous knowledge and science in the formulation of environmental policy (Forsyth, 1996; Murdoch and Clark 1994). However, adequate care should be taken in conducting such studies, as illustrated below by

Forsyth's (1996) study involving tapping and making use of indigenous knowledge for environmental management purposes in northern Thailand:

Forsyth's (1996) study involved tapping and using indigenous knowledge from local farmers in northern Thailand to test a long-standing assumption that land shortage had caused greater cultivation of steep slopes, and that erosion was a major cause of environmental degradation for hill farmers in the region. During the study, Forsyth (1996) acknowledged that assessing farmers' perceptions was 'notoriously difficult'. For instance, he found out that communication of concepts relating to environmental degradation proved to be difficult. He further explains that the common Thai expression for soil erosion (*kaan phangthalay khong din*) literally means 'the falling down of soil' and so was initially confused with 'landslides', which villagers denied happened in the region. However, through discussions with informants and interpreters, the issue was clearly explained to the villagers, enabling local knowledge about erosion to emerge (Forsyth, 1996). Due to this and other difficulties, the study had to be conducted over many months. A variety of techniques was used to reduce dependency on one method alone. Most questioning was conducted with key informants who were selected for their knowledge of the village and of farming problems. These included the high priest and previous village leader, the 'current' village leader; a woman noodle-shop owner and various male and female heads of households. Information from these informants allowed the construction of a semi-structured questionnaire for 62 randomly selected households (out of approximately 110) on the nature of land use and perception of environmental degradation (Forsyth, 1996). From the experience gained during the research, Forsyth (1996) has suggested that with respect to studies regarding environmental degradation in areas like northern Thailand, a more constructive route is to use local knowledge as the starting point in research, and to use Western science as the means to extend the results to wider areas for environmental management purposes.

It is noteworthy that in a recent study in Ghana in which information was solicited from local communities in a mining area among other stakeholders (Domfe, 2003), open-ended questions were used to obtain qualitative information from a cross-section of the community, encouraging respondents to reflect and speak at length on issues. In fact, a similar approach was used during focal group meetings / discussions in this study (see Section 3.7.2). The opinions gained from these meetings are incorporated into the results of the community surveys reported in Chapter 6 of the thesis.

Following the lessons learnt from the current study, it would be worthwhile in future research on the perception of mining-related environmental and socio-economic impacts by rural communities in Ghana to consider the following issues carefully before commencing the research:

- Adequate time should be devoted to explaining environmental concepts and other important issues to respondents, making provision for time to explain relevant issues to them in a language and in terms easy for them to follow
- Consideration should be given to the use of focus group and roundtable discussions, including indigenous people with adequate experiential ecological knowledge and resource use characteristics in the local area

- Stratified samples (to include 'enlightened' community members) may be used alongside random samples where the nature of the information required makes it difficult to rely solely on simple random samples from the general community
- Questions that call for ranking of impacts should not include those that may be 'difficult' for the rural communities, e.g., questions that ask for detailed ranking of severity of air, water or soil pollution
- As much as possible questions that call for ranking should be on issues the rural communities can easily relate to, e.g., distances covered to reach firewood sources over time, and frequency of sightings of game animals prior to, and after commencement of, mining operations
- In addition to asking questions on issues they can relate to, the interviewees should be assisted to adequately understand why and how impacts should be ranked, so the researcher can subject final results to conventional statistical test of significance of impacts, such as the use of the Chi-Squared (X^2) test
- The approach used in this study may be used to gather preliminary ('starting point') information mainly on the nature and types of mining-related environmental and socio-economic impacts

3.7. **Data Collection / Additional Sources of Data**

3.7.1. ***Data from Mining Companies***

Information was obtained from the mining companies through the use of the revised questionnaire, discussions and field visits with the Environmental Management Departments of the companies. After an initial meeting to discuss the questionnaire with the Environmental Management Departments of the companies, the questionnaire was given to them for completion. Due to the nature of the questionnaire, they were given up to 1 month to complete it to give them ample time to consult with other departments of the mining companies (Planning, Geological Survey, Human Resources and other departments). Aside from completing the questionnaire, each company was also asked to make copies of the following documents ('other mining company data sources'), if available, ready for collection within the 1-month period:

- Mine Plan
- Mine Layout
- Flow Diagram of the mining processes
- Concession Baseline Study Report
- Environmental Impact Statement
- Environment Management Plan
- Environmental Audit Reports
- Annual Environmental Reports
- Air-, Water- and Soil Quality Monitoring Data
- Compensation Scheme

On the day that the companies were visited to collect the completed questionnaire and the additional documents, a meeting was arranged with each company to enable portions of the questionnaire that needed clarification to be discussed. A date was also fixed for a mine site visit. Thus meetings for a discussion on the completed questionnaire were eventually held at each of the four mines. Again, field visits with the company Environmental Management Departments were carried out at all the mines. The visits were aimed at gaining a background knowledge of such issues as mining environmental impacts, waste management and other environmental management programmes 'on the ground'. Specific sites visited included active pits, waste dumps, leaching operations and ore processing sites, tailings dams and settling ponds. Rehabilitated sites and sites with on-going rehabilitation and other site-remediation programmes were also visited.

3.7.2 *Data from Rural Communities*

In each of the 16 communities, a meeting was held with the Village Development Committee (also known as the 'Unit Committee'). An interesting feature of the committee is that most of its members are reasonably educated. Again, its membership consists of a cross-section of community members including a representative from the Traditional Council (Council of the Village Chief and Elders), Traders Association and Farmers Union. The committee also includes a civil servant and at least one woman. Thus the committee, apart from serving as the 'spokesperson' for each community, also constituted a reliable focus group with which a number of issues related to the research could be discussed. Discussions were largely informal and centred around impacts of surface mining activities on the rural communities. At each village, the committee chairman was made to explain the purpose of the meeting to other members of the committee, after which they were engaged in discussions in which they expressed their opinions on various aspects of surface mining including impacts created, management of adverse impacts by the mining companies, adequacy of compensations and community expectations. The committees also provided information that helped in the sampling of the of the various community groups (see section 3.5) that were later interviewed. Again, in each village, visits were made, with some of the committee members, to selected mining-induced degraded areas (including polluted rivers and streams) close to the community.

Due to the rather low literacy level of most of the community members, questions in the final questionnaire developed for each group had to be interpreted to them in the local dialect of the study area ('Twi') and their responses used in completing the questionnaire in English personally. Thus each of the 800 respondents had to be personally interviewed, strictly following a questionnaire specifically designed for them depending on the sample group they belonged to.

3.7.3 *Data from Public Institutions*

As part of the data collection process, informal discussions were held with senior staff of public institutions with information relevant to the objectives of this study (see section 3.1), after which copies of documents and data, useful for the studying of mining impact and management issues in Ghana were collected from them. For instance, a document, 'Ghana Mining and Environmental Regulations' and available environmental monitoring results on all 4 mining areas selected for this study were obtained from the Environmental Protection Agency. A copy of the Minerals and Mining Law was also obtained from the Minerals Commission. Annual Reports on gold production levels were also obtained from the Ghana Chamber of Mines.

CHPATER FOUR

GEO-ENVIRONMENTAL CHARACTERISTICS OF STUDY AREA

4.1 Introduction

This chapter outlines the geo-environmental characteristics of the study area (the AGC, RAL, BGM and BGL mining areas and surroundings). The area is located in southern Ghana between longitudes 1° 30'W and 2° 28' W, and, latitudes 5° 30' N and 6° 48' N (see Figure 3.1 – Chapter 3). Specific locations of the four mines and the area covered by operations of each mine are presented in Table 4.1. The mine plans of the four mining companies have been shown in Figures 3.6 – 3.9 (Chapter 3).

Knowledge of environmental characteristics – especially topography, geology / soils, climate, hydrology and land use – of a mining area and its surroundings is necessary for the design of environmental management programmes that can effectively reduce adverse mining impacts. In fact, 'geographical and locational factors' should be given due consideration in all environmental management programmes at a mine, since these factors, to a very large extent, control both the nature and extent of environmental impacts from mining (Down & Stocks, 1977). McQuade & Riley (1996), for instance, have proposed that in designing water management systems for a mine site, data on the following environmental attributes must be collected as soon as a prospective orebody has been identified:

Table 4.1: Location and Size of the four selected Mines in the Study Area

Mining Company	**Location of mine**	**Total area of Mining concession**	**Area of concession occupied by current mining operations**
AGC	Between longitudes 1° 30`W and 1° 47` W, and, latitudes 6° 02` N and 6° 15` N in the Adansi West District of the Ashanti Region of Ghana (Site 1: Figure 3.1)	25,900 ha	964 ha
RAL	Between longitudes 1° 55`W and 2° 03` W, and, latitudes 6° 20` N and 6° 23` N in the Amansie West District of the Ashanti Region of Ghana (Site 2: Figure 3.1)	5,540 ha	326 ha
BGM	Between longitudes 1° 48`W and 2° 18` W, and, latitudes 6° 35` N and 6° 48` N in the Amansie West District of the Ashanti Region of Ghana (Site 3: Figure 3.1)	6,500 ha	6,000 ha
BGL	Between longitudes 1° 48`W and 2° 28` W, and, latitudes 5° 30` N and 5° 47` N in the Wassa West District of the Western Region of Ghana (Site 4: Figure 3.1)	9,800 ha	2,900 ha

- Climatic variables – rainfall, evaporation, wind speed / direction and net radiation which provide an indication of net water inputs and losses and their variability
- Hydrological and hydrogeological information – stream runoff, stream water quality, catchment areas and characteristics including infiltration properties of the soils, erodibility of the soils and landform slope. Information on water table fluctuations, hydraulic characteristics of aquifers, aquifer recharge zones and aquifer water quality should also be obtained. This information is critical in defining the distribution of water through a site's hydrologic cycle
- Geochemical characteristics of the rock material – especially, its potential of being a source of environmental pollution
- Biological baseline surveys, particularly, of aquatic ecosystems where discharge or seepage may impact on the health of the system

The climatic data will contribute to the preparation of an operational water balance, identifying possible periods of water excess and water deficit, and strategies for conserving or disposing of water (McQuade & Riley, 1996). While insufficient rainfall may lead to shortages in water supply, compromise the integrity of wetlands and create water deficits for the establishment of vegetation, an excess of water may lead to offsite disposal problems, erosion, structural instability of landforms, and increased road maintenance and flooding of infrastructure and pits. The measurement of precipitation – its form, frequency, spatial variability, intensity and duration – is therefore mandatory for the design and successful implementation of any mine water management system (McQuade & Riley, 1996). Bell (1996) has also emphasised the need for adequate knowledge of the following environmental characteristics for effective mine planning, especially, towards the later stages of the mining cycle:

- Topography – while the topography of the post-mining landscape dictates the type of land uses and erosion potential, the pre-mining topography is an essential baseline from which to calculate the elevation and slopes that can be achieved with subsequent reshaping of waste dumps. An examination of slopes both within and surrounding the mine site will indicate the degree of reshaping needed to achieve visual blending of waste dumps with the surrounding terrain. It will also highlight areas where, due to constraints imposed by mining methods, surface features or economics, steeper slopes will need to be constructed which in turn may dictate special considerations for revegetation and subsequent land use
- Soils, Rocks & Overburden – geologists commonly use overburden samples obtained from the mining area to gain information relevant to future mine development: the hydrological consequences of mining; the occurrence of potentially hazardous faults; the blasting requirements; and future stability of waste rock piles. These overburden samples should also be retained for measurement of properties relevant to the future rehabilitation programme, including (i), the presence of potentially toxic materials such as sulphides which may lead to major water quality problems during and after mining, and (ii), the ability of various strata to support plant growth. Such information is necessary for early decisions to be made regarding selective placement of toxic strata and whether soil retention and replacement on the excavated overburden is required

- Climate – the amount, distribution and variability of precipitation together with evaporation and temperature patterns have a marked effect on the nature and success of a rehabilitation programme through their effect on vegetation and on erosion. The total yearly precipitation, its type and its seasonality have a substantial influence on the type of vegetation which can be grown successfully; in general, the higher the annual rainfall the easier it is to grow most types of vegetation. A high annual rainfall is less effective, however, if it all occurs in the form of heavy intensity storms during a few months of the year
- Pre-mining Land Suitability and Use – the pre-mining condition of the land provides a guide to the options available for post-mining land use. Documentation of the state of the land prior to mining also provides a benchmark from which the eventual success of rehabilitation may be judged

Characteristics of the study area that make it particularly vulnerable to mining-related environmental pollution and / or degradation in the absence of appropriate Environmental Management System(s) include the following:

- Topography – the area is predominantly a deeply dissected landscape drained by several rivers and streams. Associated with such a landscape are fluvial erosion, siltation, catchment ecology- and water quality problems, among others
- Geology / Soils – the study area is characterised by sulphidic ores containing pyrites and arsenopyrites. The soils are generally well drained, highly leached and acidic with low Cation Exchange Capacity (CEC) and poor Buffering Capacity. Issues of concern as far as these geological and soil attributes are concerned include Acid Mine Drainage (AMD), soil and ground water

pollution, soil and air pollution, and, disturbance and / or pollution of terrestrial and aquatic ecosystems

- Climate – the area is characterised by high intensity rainfall with wide variation in wet and dry season monthly maxima, and, a pronounced windy dry season. Issues of concern arising from these climatic phenomena are wind erosion and soil loss, flooding and siltation, water quality / pollution, terrestrial and aquatic ecology and health, and, dust / atmospheric pollution
- Hydrology – the region is drained by many perennial and ephemeral streams characterised by high discharge rates during the wet months of the year, and very low discharge rates in the dry months. Environmental issues of concern under such hydrological conditions include flooding, water quality, concentration of pollutants and, sustainability of terrestrial and aquatic ecology
- Landuse – the predominant landuse in the study area comprises human settlement, agriculture, logging and gathering of forest products. This makes the need to ensure habitat safety / security, enhancement of community survival and minimisation of soil, air and water pollution in the study area an issue of crucial importance

The sections below describe the geo-environmental setting / site characteristics of the study area in detail. Information for the general description of the geo-environmental characteristics of the area was extracted from Dickson & Benneh (1988), Kesse (1987), Boateng (1959), and, data from the Ghana Meteorological Services Department (2002) and the Water Resources Research Institute [Ghana] (1992). For each mine, the description of site characteristics specific to it was derived from the sources above together with the Environmental Impact Statement and / or Environmental Management Plan for the mine in question (AGC, 1999; RAL, 1995; BGM, 1998; BGL 2000).

4.2 Geo-environmental setting

The geo-environmental characteristics of the study area are described below.

4.2.1 *Topography*

A range of hills whose valleys are drained by various streams and their tributaries dominates the landscape of the study area. Specific topographical features of the various mine sites are as follows:

i. AGC mining area – the concession is located on a landscape with elevations between 150 – 450 m. The streams which drain the valleys flow either to the west and north-west into the Jimi river or to the south into the Ofin river.

ii. RAL mining area – the concession is covered by a series of low to gently undulating hills, most of which rarely exceed 680 m in elevation. The Ayensu and Subin rivers, and the Kotia and Adubia streams, which flow into the Ofin River, drain the valleys of these hills.

iii. BGM mining area – elevations on the concession range from 205 to 540 metres. The area is drained by Rivers Jeni and Bonte. The land rises sharply from the river valleys, with well-developed alluvial terraces in the western part of the lease.

iv. BGL mining area – the area is hilly, with the hills running through the centre of the concession. The hills are aligned with the main gold bearing ores, and are the location of the majority of the mining activity in the concession. The general level of elevation varies between 152 m and 305 m but this is occasionally broken by hills 500 m – 650 m in elevation. There are two main catchments in the concession. The Mansi River and its tributaries (which form the more significant of the two catchments) drain the area to the west of the hills, while the Bojiri River and its tributaries drain the eastern area. Both of these rivers flow ultimately into the Ankobra River.

4.2.2 Geology / Soils

The study area is underlain by two major geologic formations, namely, the Birimian System with associated granite intrusives, and the Tarkwaian System (Figure 4.1). The Birimian System is divided into the Lower Birimian which consists of metamorphosed sediments such as phyllites and schists, and the Upper Birimian which is the younger of the two and consists of rocks of the Lower Birimian as well as metamorphosed lavas. Associated with the Birimian formation are extensive masses of granites formed through the cooling of magma.

The soils in the region are generally porous, well drained and loamy, and are developed over a wide range of highly weathered parent materials including granite, Tarkwain and Birimian rocks. The reaction of the rocks ranges from highly

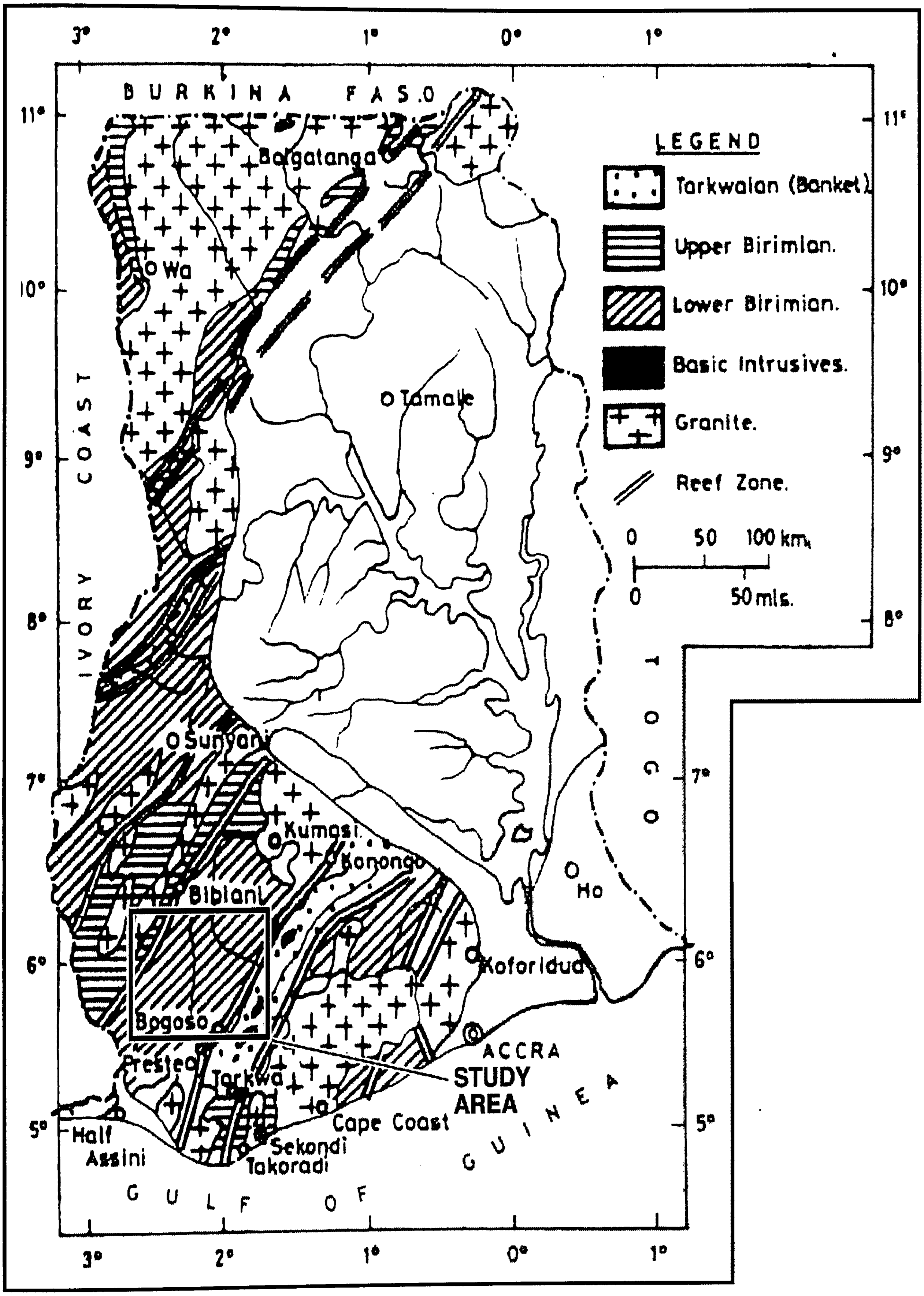

Figure 4.1: Geological Map of Ghana showing Gold Reef Zones (Modified from Kesse, 1985)

acidic (especially in the BGL mining area) to slightly alkaline (in the BGM mining area). 'Specific' characteristics of the geology / soils at the various mines are summarised below. In describing the soils, the FAO / UNESCO Soil Classification System has been used. Where the 'Local System' of soil classification is used, it's 'FAO / UNESCO equivalent' is given, in parenthesis.

4.2.2.1 *AGC Mining Area*

A major part of the concession is overlain by young clastic quartz-rich sediments of the Tarkwaian Group. Metavolcanic rocks in the form of mafic flows and volcanoclastic sediments occur in the north-western boundary of the concession which is best known for its numerous significant gold deposits that have an extensive mining history. To the west of the volcanic units occurs the Birimian metasediments described as a thin to thickly bedded sequence of turbidic greywackes, spotted and carbonaceous shales and argillites. Close to the volcanic contact, these sediments are strongly sheared and contain quartz veins. The concession is predominantly underlain by Birimian sediments and minor volcanic rocks to the west, and Tarkwaian Group metasediments and basic intrusive rocks to the east, with Birimian age rocks underlying approximately 40% of the area. To the east of the volcanic unit lies steeply west-dipping sequence of carbonaceous argillites and greywackes extending to the Tarkwaian contact. The steeply east-dipping Tarkwaian sediments consist of a basal, poorly sorted conglomerate, otherwise known as the Kawere formation which occurs at the fault contact with the Birimian sediments. These grade up into a magnetite-bearing quartzite (Blanket Group) which in turn, is overlain by phyllites and sandstones on the eastern side of the concession. Gold in the area is associated with disseminated sulphides (3-15%) consisting of pyrrhotite, pyrite and arsenopyrite, contained within a steeply west-dipping iron-rich sediment that has been metamorphosed and subjected to metasomatic alteration. Garnets up to 0.8 cm in diameter and coarse amphiboles have formed in the zone which has subsequently acted as a host for fine grained gold and sulphide mineralisation.

The soils in most parts of the concession developed from weathered Tarkwaian rocks and belong to the Dampia-Mawsu Soil Association. On the western part of the concession, the soils have largely developed from weathered Birimian rocks and belong to the Ansum-Oda Soil Association. The Dampia Series (*Lithic Leptosol*) are found on summits and upper slopes in mountainous areas with steep rolling topography. They are brown, shallow, rocky, well drained acidic soils with granular structure grading into rock brash and undecomposed hard rock. The Mawso Series *(Ferric Acrisol)* are found on steep-sided upper and middle slopes of mountains and hills. They are moderately deep, well-drained, dark brown to yellowish brown in colour, acidic in reaction, concretionary gravelly and stony.

The Ansum Series *(Haplic Acrisol)* have developed on colluvial materials at the foot of hills and mountains. They are very deep (over 180 cm), moderately well drained, and sandy loam to silty-clay loam in texture.

The Oda Series (*Eutric Fluvisol*) are found on wide valleys of rivers and streams, developed on alluvial materials. They are very deep (over 200 cm), poorly drained and acidic in reaction. The top soils are 12-20 cm deep, and have a weak coarse granular structure with silty loam to silty clay textures, overlying thick structureless subsoils of grey strongly mottled to dark brown colour and clayey loam to silty clay textures.

4.2.2.2 *RAL Mining Area*

The RAL concession forms part of the Ceval Proterozoic System of the Birimian (2.17 – 2.18 billion years) meta-volcanic (arc) / meta-sedimentary (basin) rocks developed within the Kumasi basin. The Kumasi basin is generally made up of agillite and turbidite units and in places, tuffs. The ore deposit is located on the Asankragwa Corridor which is characterised by volcaniclastic and volcaniclastic / agallite facies. The rocks in the deposit consist of meta-sediments and granitoid intrusion. The meta-sediments include phyllites, carbonaceous phyllites, wacke and greywacke. Generally, greywacke domains dominate the western part of the deposit whilst the central and eastern parts are made up of the interbeds of phyllite and greywacke with phyllite dominating. Intruding the meta-sediments is lozenge-shape intrusion of inferred tonilite composition. This rock has a distinct medium to coarse-grained texture and is extremely altered and veined. Most of the gold in this region is locked in sulphide minerals. During weathering, the sheared (Birimian) rocks disintegrate, liberating the gold. Similarly, oxidation of the sulphides releases the gold.

The soils in the concession fall within the Bekwai-Nzima / Oda compound associations. This association which occupies over 90% of the area consists of individual soil units of the Bekwai and Oda series. The Bekwai series (*Ferric*

Acrisol) are found on the summits and upper slopes of the hills in the area. They are generally deep to very deep (over 20 cm), humus, well-drained, red in colour, loam to clay loam, gravelly and concretionary, with well-developed sub-angular blocky structure and clay cutans within the subsoil. A typical profile of the Bekwai series consists of thick topsoil of up to 19 cm of dark brown to dusky red, humus-stained, loam to clay loam, weak fine granular structure with moderate acidic reaction. The Oda series (*Dystric Fluvisol*), on the other hand, are heavy-textured soils developed on alluvial deposits along streams in the area. They are poorly drained soils and are subjected to flooding during the wet season, and are greyish in colour with prominent yellowish orange mottles. The soils are deep and acidic, with clay loam to clay textures but are structureless in the subsoil. Few quartz gravels and stones may be encountered at the base of the profile.

4.2.2.3 *BGM Mining Area*

The BGM concession lies in the northeastern trending Asankragwa-Manso-Nkwanta gold belt. The consolidated rocks in this section of the belt consist of early Precambrian basement phyllites, schists, slates and metagreywackes of the Lower Birrimian System. These rocks are complexly folded as a result of several major tectonic episodes of deformation that occurred in Precambrian time. The cover on the basement rocks consists mainly of Tertiary to Recent alluvials, mainly gravels, sands, and silty clay in river valleys, and semi-consolidated laterites on the higher ground. The weathering profile generally possesses low permeability. The partially decomposed rock underlying the surficial sandy-clay material is much more permeable and acts as a drain for the sand-clay zone.

Soils in the area are essentially lateritic, having been formed as residual products of intense chemical weathering of the phyllitic bedrock and associated quartz veining. They may generally be described as firm to stiff, gravelly silty clay soils of high plasticity; typical plasticity indices vary between 28% and 33%. The soil thickness varies between 1 m and 4 m, with the moisture content ranging from 8% to 23%.

4.2.2.4 *BGL Mining Area*

The BGL concession lies at the edge of the West African Craton. The geology comprises (in order of increasing age):

1. 10 - 40 m of weathered regolith,
2. Tarkwain sequence consisting of conglomerates, quartzites and phyllites, and
3. Proterozoic Birimian sequence consisting of pelites, greywackes and occasional basic volcanics.

A north-east trending system of ridges is located to the east of the ore deposits within the concession. The main ridge sytem roughly corresponds to the contact between the Birimian Group to the west and the Tarkwaian Group to the east. The Birimian Group, which hosts the ore deposits, consists of fine-grained interbedded phyllites, carbonaceous shale, tuff and greywacke, and mafic metavolcanics and dolerite sills. The surficial geology is characterised by intense weathering. The primary gold mineralisation is in the 'crush zone' (so called because of the presence of brecciated small-sized quartz fragments) which has a strike length of about 18 km on the concession. The gold deposit consists of oxide, transition and sulphide ores. Other minerals in the area include carbonates, sericites and chlorites, indicating very low grade metamorphism with predominant mylonitisation. The lodes are in lensitic bodies averaging half a kilometre in length, 10 to 15 m thick and dip 65° westerly. *Lithic Leptosols* and *Ferric Acrisols* [which have been described in Sections 4.2.1 (a) and (b)] dominate the soils in this region.

4.2.3 ***Climate***

The study area lies within the moist semi-decidious forest zone of Ghana, which has associated with it a Wet Semi-Equatorial Climate. The seasons in this region are influenced by the moist, south-western monsoon winds from the Atlantic Ocean and dry, dust-laden north-east trade winds ('Harmattan') which blow over the Sahara Desert from the northern sub-tropical high pressure zone. The region experiences two rainfall maxima, with a mean annual rainfall of between 1250 and 2000 mm. Beginning from March, it attains the first peak in June (with a mean monthly rainfall of 240 mm). The rainfall then decreases sharply till August and rises again to reach a second peak in October (with a mean monthly rainfall of around 173 mm). The two periods of heavy, high intensity rainfall (May to June, and, September to October) are interspersed by dry seasons (late July - August and November to March). Figure 4.2 shows typical monthly rainfall patterns in the study area. The dry seasons are quite sharp and pronounced. The highest mean temperature of about 30°C occurs between February and March while the lowest of about 26°C occurs in July and August. The mean annual pan evaporation rate in the region is between 1429 mm and 1576 mm (3.92mm and 4.32 mm / day). The mean monthly relative humidity in the area increases from a minimum value of 65% in

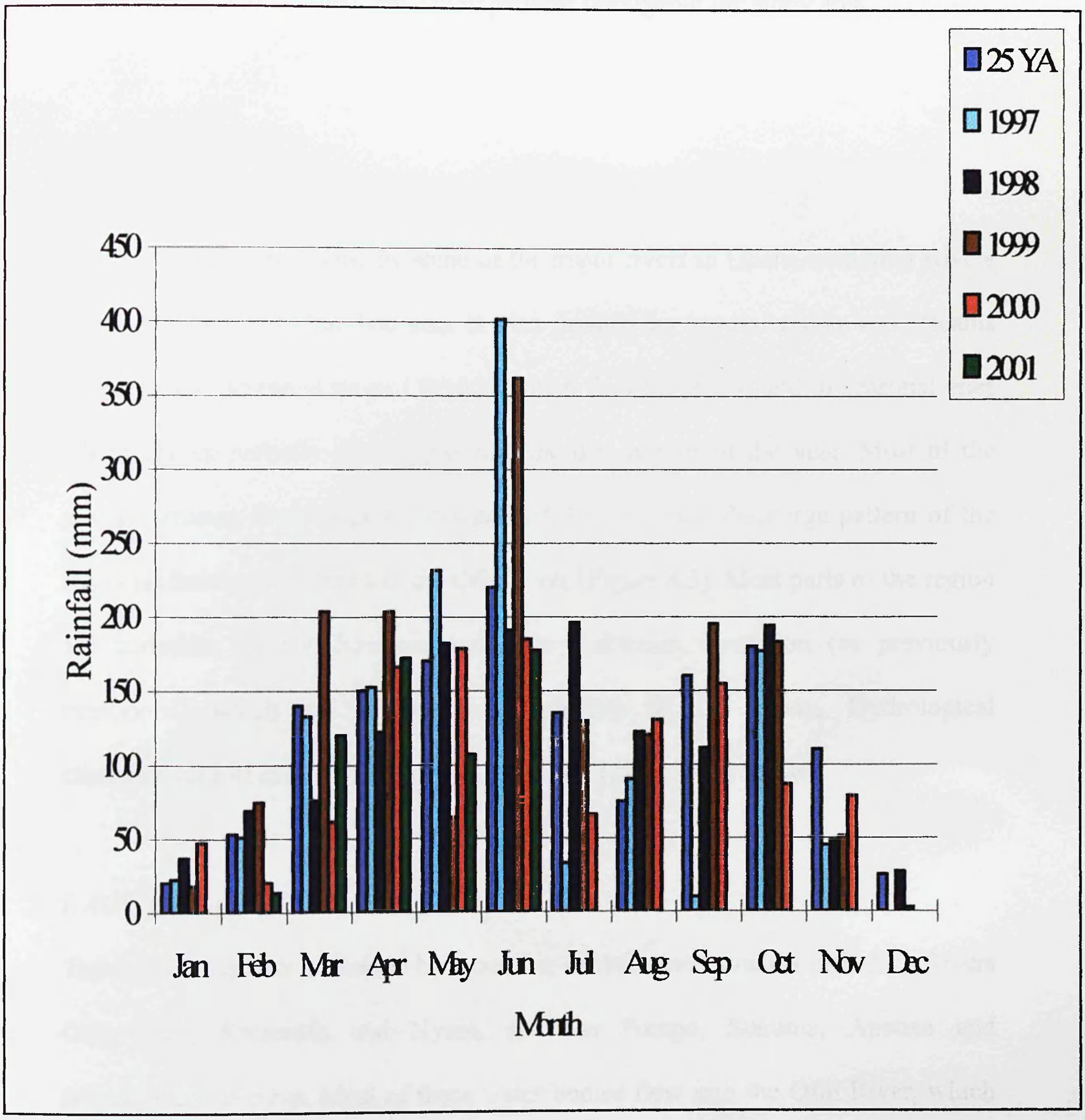

Figure 4.2: A typical Monthly Rainfall Pattern in the Study Area (1997 to 2001) & Average Monthly Rainfall over a 25-year Period (1976 to 2001) [Derived from rainfall data from the Ghana Meteorological Service's Ashanti Bekwai Weather Station (1976 – 2001)]

February to a maximum of about 81% in July and August. Climatic data on the study area from the Ghana Meteorological Services Department show a general uniformity in rainfall and temperature patterns throughout the study area.

4.2.4 *Hydrology*

The study area is traversed by some of the major rivers in Ghana including Rivers Ofin, Ankobra and Pra. The area is also drained by several rivers and streams ranging from perennial rivers / streams which flow all year round to seasonal ones which dry up partially or totally during the dry months of the year. Most of the rivers / streams in the area are not gauged, but a typical discharge pattern of the rivers is illustrated by flows in the Ofin River (Figure 4.3). Most parts of the region are underlain by the Birimian and / or Tarkwaian formation (as previously mentioned) which act as the main aquifers in the region. Hydrological characteristics of each of the four mining areas are described below.

i. *AGC Mining Area*

The concession area is drained by a number of rivers and streams including Rivers Ofin, Jimi, Kwabrafo and Nyam, and the Pompo, Sukuma, Apetisu and Akyekyeresu streams. Most of these water bodies flow into the Ofin River, which in turn flows into the Pra River which eventually joins the Atlantic Ocean between Cape Coast and Takoradi. While many of the water bodies (e.g., Ofin River, Jimi River and Akyekyeresu stream) are perennial, most of the streams draining the concession are seasonal and dry up totally or partially between December and April. The concession falls within the Birimian (geological) System which is

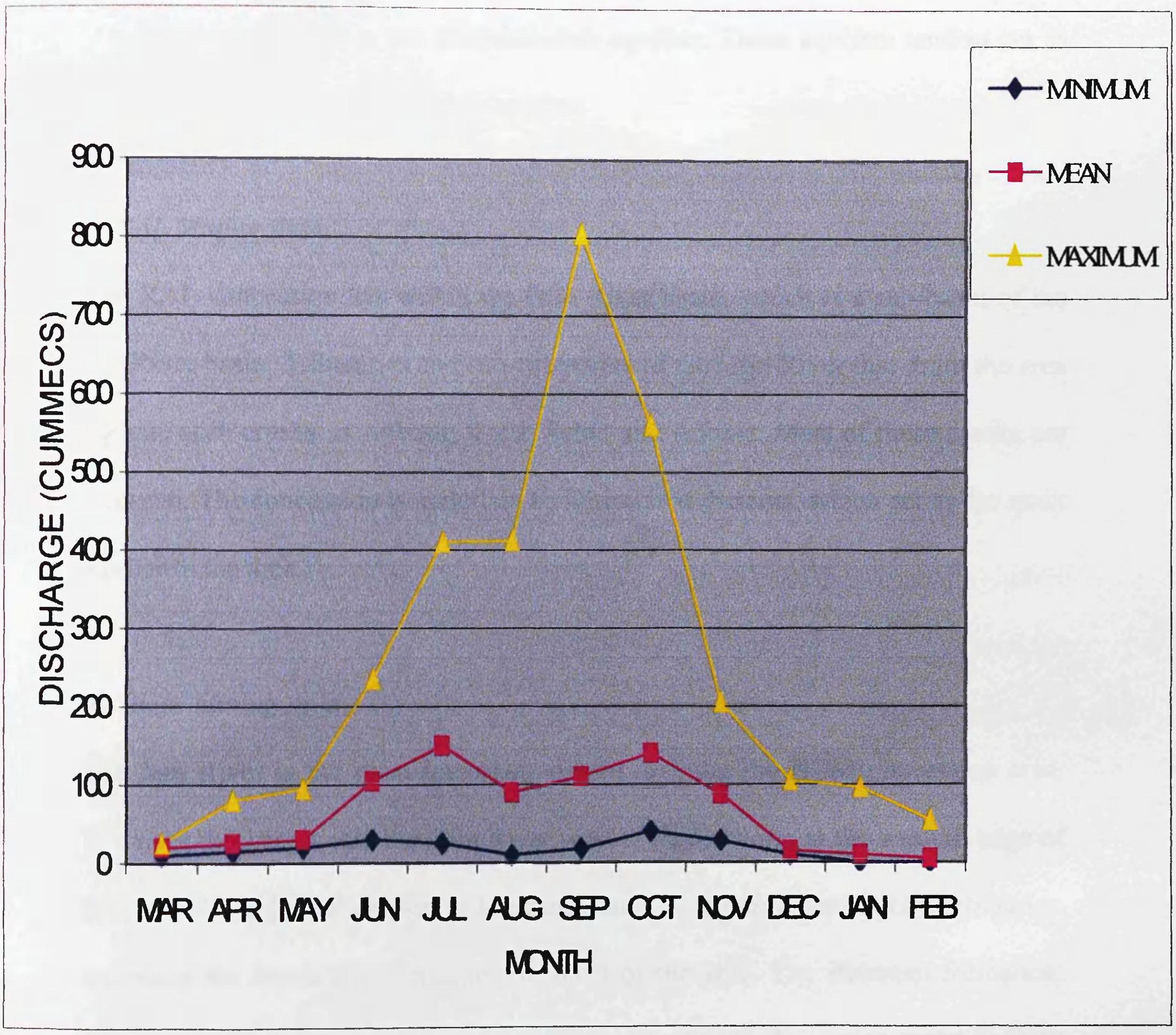

Figure 4.3: Monthly Flow Characteristics – River Ofin at Dunkwa (Modified from Water Resources Research Institute of Ghana [WRRI], 1992).

known to yield relatively substantial amounts of groundwater, particularly, where the rocks are highly weathered, fractured and / or interbedded with quartz veins. Where the rocks outcrop or lie near the surface, considerable water may penetrate through the joints, fractures or other openings, especially, if such partings are not filled with impermeable weathered products. The bedrock is not inherently permeable, but has secondary permeability or porosity developed as a result of fracturing and weathering. In general, two types of aquifers are identified, namely, weathered rock aquifers and fractured rock aquifers. These aquifers tend to act as confined or semi-confined (leaky) aquifers.

ii. *RAL Mining Area*

The RAL concession lies within the Ofin River basin, which is a sub-basin of the Pra River basin. Tributaries and sub-tributaries of the Ofin River that drain the area include such creeks as Ayensu, Kotia, Subin and Adubia. Most of these creeks are seasonal. The concession is underlain by Birimian sediments, which act as the main aquifer in the area.

iii. *BGM Mining Area*

The Jeni River is the most important stream draining the BGM concession area. The river discharges into the Ofin River west of Adobewora, at the western edge of the 'Jeni River Lease' section of the concession. The Jeni River and its tributaries, including the Bonte River, are dry for most of the year. The Birimian formation, which underlies the area, is considered to be one of the major water-bearing formations in Ghana. There is a great deal of variability in the permeability of these rocks. The natural discharge of groundwater along the valley bottoms is primarily through evaporation from the water table and through trees and shrubs. Groundwater contribution to the base flow of streams is generally low, and evaporation from the river beds in the dry season removes the groundwater as quickly as it moves upwards, except in the lower reaches of the Bonte River, where intermittent surface flow occurs.

iv. *BGL Mining Area*

The entire concession is within the Ankobra River basin. The site is drained by numerous streams, many of which are ephemeral and dry up during parts of the year. Most of the rivers drain towards the western part of the concession and discharge into the Mansi River. The Mansi flows southwards and joins the Ankobra about 8 km north of Prestea. The eastern portion of the concession drains into the Bojiri River, which flows south-west and eventually discharges into the Ankobra River near the town of Awodwa. Two distinct aquifers are found in the area; an upper unconfined unit contained within weathered overburden and a lower semi-confined fissured bedrock aquifer. Groundwater flow in the bedrock aquifer occurs primarily through a network of fractures created by tectonic forces. The fissured bedrock consequently has localised high permeability and low storage capacity. Static water levels in boreholes around the concession have been found to be similar to surface river water levels suggesting that there is continuity between the surface and groundwater systems. Indirect recharge of the bedrock aquifer occurs by downward leakage of rainwater through the overburden, and direct recharge is thought to occur along the crest of a north-east / south-west ridge where the bedrock is closest to the surface.

4.2.5 *Land Use*

There is a general uniformity in land use types throughout the study area. Apart from large scale mining, the major categories of land use in the area are farming, fishing, forestry and logging, gathering of forest products, hunting and human settlement. A small section of the local community also engages in artisanal gold mining ('Galamsey'). Farming is the most widespread primary occupation of the rural communities in the area. Bush fallowing and permanent cultivation techniques are widely adopted for the cultivation of cocoa, oil palm, citrus fruit and the production of food crops such as plantain, cocoyam, cassava, maize, yam and vegetables. Another occupation is the gathering of a wide range of forest products including wild fruits, raffia and bamboo for roofing. Harvesting of sponges, fuelwood, poles for construction and medicinal herbs is also undertaken by some of the people in the region. The landuse types in the region are described in detail below:

4.2.5.1 *Bush Fallow Agriculture / Shifting Cultivation*

The bush fallow system of farming is characterised by cutting and burning of the forest and mature fallow land. The plot is cleared and planted with crops, mainly vegetables, cocoyam, cassava, plantain and maize. Cultivation and harvesting are done for two or three seasons and the plot is left to fallow for periods varying according to the demand for land and the nature (fertility) of the soil. The farmer cultivates new plots of land as soon as he abandons the old one. Three years to ten years is the period during which most farmed land is allowed to revert to bush before being cleared again for cultivation. However, in sparsely settled areas, it may take as long as 15 years before an abandoned piece of land is brought under cultivation again.

Shifting cultivation, a form of bush fallowing system of farming which used to be common in the forest zone of Ghana when land was in abundance and population was scarce, is practised only to a limited extent in the study area. This system involves the movement or 'shifting' of both settlements and farming to new areas when old farms are abandoned. This system was particularly popular in the 'olden' days when lack of transport made it difficult for farmers to commute between their homes and their new farms on a daily basis, especially, if the farm was very far from their area of residence.

4.2.5.2 *Cash Crop Cultivation / Mixed Cropping*

Cocoa plantations are cultivated in several places in the study area. Isolated oil palm plantations are also identified. The younger cocoa and oil plantations are intermixed with food crops (mainly plantain, maize, cassava and cocoyam). In addition to these crops, tomatoes, okro, garden eggs, pepper, pineapples and onions are cultivated in many parts of the region.

4.2.5.3 *Forest Products Gathering*

Forest products gathering in the study area involves the collection of fruits, bamboo, building materials, medicinal herbs / products, firewood, snails, mushrooms and game. Other products yielded by the forest include chewing sticks, bath and chewing sponges. In most of the region – which falls within the moist semi-deciduous forest zone of Ghana – the oil palm tree, which is of great local importance, grows wild. From its fruits are obtained pericarp and kernel oil, while the stem yields a popular and potent drink known as palm wine, from which an even more potent gin locally called *akpeteshie*, can be distilled. The leaves and brances of the tree are used for a variety of purposes including building, roofing, and basket making. With the oil palm tree are associated also the raffia palm (from which raffia is obtained) and the cane palm (from which cane is obtained), both of which are found in swampy areas. Raffia and cane are used locally in basket and furniture making, both for local use and for export.

4.2.5.4 *Livestock Production, Fishing and Hunting*

Livestock production in the region is normally on a small scale, mainly for household consumption. Sheep, goats and poultry reared in the area are usually confined to the villages and hamlets.

Although fishery resources used to abound in many parts of the area, currently there is no organised fishing or management of this resource. During the rainy season, hooks and traps are used – mainly by the youth and children – for catching crabs and fish in some of the streams draining the region.

In the past, hunting for game (both for household consumption and for sale) used to be a very important activity in the study area, and many parts of the forests in the region were dotted with small hunters' camps. However, currently, due to mining, farming and other activities, several species of game animals have moved away to more favourable environments.

4.2.5.5 *Human Settlement*

A dominant feature of the region's landscape is a large number of hamlets and villages. A typical settlement pattern consists of compact groups of mud houses with thatch roofing covering relatively small areas. The settlements primarily serve two purposes – they provide accommodation for the rural population and other migrant settlers (including mine workers) and a centre for social life, in which the chief and various religious officials play a leading part. In most cases, the chief's house and the spot where religious rites are observed form the core of the settlement and provide a nucleus around which the houses of the inhabitants are grouped.

CHAPTER FIVE

RESULTS: MINING COMPANY DATA

5.1 Introduction

A field survey was undertaken at the four selected mines between 21 February and 10 May 2000 to ascertain the impacts of surface gold mining activities on the environment and communities in the study area. The survey was also to help find out about environmental management and other programmes put in place at the mines to minimise adverse impacts of, or enhance the positive impacts associated with, mining operations. This information was obtained through the use of a questionnaire (Appendix 17) and by interviewing appropriate personnel at the mines (see Section 3.7.1). The questionnaire was designed to solicit information on the types of methodologies / techniques that were employed in the collection of baseline data prior to the commencement of mining operations. This was to help ascertain whether proven or 'standard' methodologies were used. Unfortunately, however, only AGC Limited gave adequate information on specific methodologies / techniques that were used for baseline data collection for its Ashanti Mine Expansion Project (AMEP). Statements such as 'Standard methodologies were used in the collection of air and water samples,' used in the completion of the questionnaire are of very little help, especially when it comes to verification of the effectiveness of the methods used. It is hoped that in future, EPA (Ghana) makes it mandatory for the methodologies used in baseline data collection to be clearly spelt out by proponents of all major projects.

In addition to the use of the questionnaire and personal interviews, field visits were also carried out with personnel of the Mining Company Environmental Management Departments in all four mining areas, to physically observe environmental management programmes on the ground. It must be stated that many of the negative impacts created at the four mines were found to be similar in nature and are presented in Table 5.1. The remaining sections of this chapter outline the gold mining process at each of the mines and the positive impacts associated with mining activities. Measures employed at each mine to minimise adverse mining impacts are also presented.

5.2 **AGC Limited**

AGC has been mining gold in the Adansi West District of the Ashanti Region of Ghana since 1897. The company had been operating underground mines in and around Obuasi until 1989 when it commenced surface mining operations in areas within its 25,900 ha concession found to have economic quantities of near-surface ore. It came to light during the field survey that although AGC's operations had resulted in the creation of several undesirable environmental and social impacts, a number of measures had been put in place to mitigate the adverse impacts of their operations. Among other measures, the company had established an Environmental Management Department armed with a well-defined Environmental Policy, an Environmental Management Programme and a Reclamation Plan. A Compensation Scheme had also been put in place to help reduce the adverse socio-economic

Table 5.1: Summary / Comparison of Adverse Impacts created at the four Mines

Mine / Sources of Adverse Impacts		Environmental Features Impacted Upon							
	AIR EMMISSIONS	Surface Water	Ground Water	Air Quality	Soil & Landuse	Flora / Fauna	Local Community	Land-scape	Cultural Heritage
Ashanti Goldfields Company Limited	Vegetation Clearance (Dust / Noise from mine vehicles)			♦		♦	♦		
	Blasting / Ore extraction (Dust / Noise)			♦		♦	♦		
	Ore Loading / Haulage / Transport (Dust / Noise)			♦		♦	♦		
	Ore Stockpiling (Dust / Noise)			♦		♦	♦		
	Waste Rock Disposal (Dust / Noise)			♦		♦	♦		
	Crushing / Milling (Dust / Noise)			♦		♦	♦		
	Ore Roasting / Smelting (SO_2 / AS_2O_3)			♦		♦	♦		
Resolute Amansie Limited	Dust & Noise from vegetation clearance, blasting, haulage. ore stockpiling and waste rock disposal activities			♦		♦	♦		
	Air Pollution from waste rock disposal (dust / noise), crushing / milling (dust / noise) and smoke from vehicle exhausts and process gases			♦		♦	♦		
Bonte Gold Mines Ltd.	Noise (pollution) from excavation machines / processing (washing) plant			♦		♦	♦		
	Air pollution from dust from haulage trucks / other mine vehicles, and from site preparation activities			♦		♦	♦		
Bogoso Gold Limited	Dust from tailings dams, haul roads, unvegetated ground, waste rock dumps, stockpiles and vehicular movements			♦		♦	♦		
	Noise / dust emissions from mine vehicles and processing plant			♦		♦	♦		

Table 5.1 Ctd.

Company	WASTE / RUNOFF WATER & LIQUID EFFLUENTS	Surface Water	Ground Water	Air Quality	Soil & Landuse	Flora / Fauna	Local Community	Land-scape	Cultural Heritage
Ashanti Goldfields Company Limited (AGC)	Devegetation during site preparation and consequent increased erosion	♦			♦	♦	♦		
	Runoff from stockpiles, haul roads and waste dumps following rainstorm	♦	♦		♦		♦		
	Residual cyanide from Heap Leach operations (spillage of cyanide solution into the environment & seepage of cyanide soluion into the ground beneath the heap leach pads)	♦	♦		♦	♦	♦		
	Contamination by Dissolved Cyanide and Arsenic following spills from tailings dams during planned discharge of excess dam water into nearby streams (mainly, Rivers Nyam and Kwabrafo)	♦	♦			♦	♦		
RAL	Increased runoff from cleared areas	♦			♦	♦	♦		
BGM	Creation of pools of stagnant water with potential for spread of water-borne diseases, especially, malaria						♦	♦	
Bogoso Gold Limited (BGL)	Exploration drilling	♦	♦			♦	♦		
	Pit-dewatering	♦	♦			♦	♦		
	Runoff from site roads, waste dumps, stockpiles, plant yard and processing plant into the environment (including Lake Marwood and the Nogoro Creek)	♦	♦			♦	♦		
	Leakage of process chemicals (including cyanide) and leakage / spillage of oils / fuels / liquid reagents into the environment	♦	♦			♦	♦		
	Occasional tailings leakage from pipeline & seepage from tailings dam		♦				♦		
	Surplus supernatant water discharge from tailings dam	♦	♦			♦	♦		
	Accidental spillage of fuel, oil or chemicals during transport to and from mine	♦	♦			♦	♦		

Table 5.1 Ctd.

	SOLID WASTE	Surface Water	Ground Water	Air Quality	Soil & Landuse	Flora / Fauna	Local Community	Land-scape	Cutural Heritage
A G C	Waste rock / Waste Dumps	♦	♦	♦	♦	♦	♦	♦	♦
	Refuse (including laboratory waste)	♦	♦	♦	♦	♦	♦		
R A G	Waste rock / Waste Dump	♦	♦	♦	♦	♦	♦	♦	
B G M	Temporary Waste Dump	♦	♦	♦	♦	♦	♦	♦	
B G L	Waste rock / Waste dumps	♦	♦	♦	♦	♦	♦	♦	♦
	Refuse (including laboratory waste)	♦	♦	♦	♦	♦	♦		
	Disposal of used storage containers, empty cyanide boxes, scrap, workshop waste, used tyres and batteries	♦	♦				♦		

	IMPACTS AFFECTiNG LOCAL COMMUNITIES	Surface Water	Ground Water	Air Quality	Soil & Landuse	Flora / Fauna	Local Community	Land-scape	Cutural Heritage
A G C	Destruction of farms / farmlands of rural communities				♦		♦		♦
	Disturbance to rural community due to occasional flyrock associated with blasting						♦		
R A L	Destruction of farms, forests and other resources of local communities				♦		♦		♦
BGM	Destruction of farms, forests and other resources of local communities				♦		♦		♦
B G L	Destruction of farms and forests and scaring of game from their habitats and consequent impact on farming and hunting					♦	♦		
	Influx of population into communities surrounding mine due to employment and commercial opportunities				♦	♦	♦	♦	♦

Table 5.1 Ctd.									
	OTHER SOURCES / IMPACTS	Surface Water	Ground Water	Air Quality	Soil & Landuse	Flora / Fauna	Local Community	Land-scape	Cultural Heritage
AGC	Changes in topography causing visual intrusion						♦	♦	♦
AGC	Reduction of surface and ground water supply through ground water abstraction and impoundment of rivers (eg. R .Jimi)	♦	♦				♦		
RAG	A general lowering of the local water table as a result of dewatering during mineral extraction		♦				♦		
BGM	Reduction of groundwater supply resulting from pit excavation and pumping of ingress water / use of abstracted water for ore processing activities		♦				♦		
BGL	Land take for mining development (especially, creation of new pits and waste dumps)				♦	♦	♦	♦	♦
BGL	Abstraction of groundwater for ore processing and subsequent reduction in available ground water to downstream communities		♦				♦		

* *The above table only summarises the types of environmental impacts associated with mining activities in the study area, and not the magnitude or severity of the impacts. A matrix – such as Leopold's Matrix (Leopold et al, 1971) – indicating the magnitude and / or severity of mining impacts would however be required, for the prediction of potential impacts in future (new) mining operations in the study area*

impacts of mining on communities close to the mine. In the sections below, the mining process and the positive mining impacts of AGC's mining activities are described. Measures undertaken at various phases of mining to minimise adverse mining impacts are also highlighted. It would be noticed that in the case of the 'Mine Closure / Decommissioning' phase of mining (section 5.2.3.5), most of the measures enumerated are those that would be put in place in 'future'. This is because, the AGC mining concession – like all the others studied – still had vast areas yet to be mined and hence had not reached this phase of the mineral exploitation process as at the time of the field survey.

5.2.1 *Mining & Ore Processing*

Conventional open-pit mining methods are employed at AGC's mine near Sansu in the Adansi-West District of Ghana. The mining operation is highly mechanised, involving drilling and blasting, excavation of the broken material, and loading of the excavated material. Mining is carried out by a fleet of Komatsu and Caterpillar equipment (including hydraulic excavators, front-end loaders, bulldozers, motor graders and dump trucks) and Holman drilling machines. After site clearance and overburden removal, drilling and blasting are employed to fragment the gold-containing rock. The drilling patterns are designed according to the mechanical and physical properties of the rock. A 4 m x 4 m staggered pattern is used for soft ground, a 5 m x 3 m staggered pattern for slightly hard rock, and 4 m x 2 m or 5 m x 2 m patterns for hard rock formations. Optimum upheaval of hard-to-rip ground is achieved through the blasting of drillholes of 5 m in depth and sub-drills of 1 m. Blasting is initiated in multiple rows, to help minimise throw and backbreak, and also to prevent the dilution that might result from overbreaking. After drilling and blasting, a grader levels the bench floor, and the mine geologist demarcates the ore and waste zones, which are colour-coded with yellow and green pegs respectively. The ore is excavated within benches of 10 m in height, in lifts of 2.5 m from the top and are advanced downwards. In other words, a 10 m bench is mined in four slices, each 2.5 m high. Depending on the depth of the pit, the ore being mined can be any of the three ore types (oxides, transition material, or sulphides), and care is taken not to mix them during their haulage. Ore losses are minimised by ensuring that all the broken ore is loaded into trucks. Special truck-despatching schedules are followed to ensure that the various ore types are taken to their designated treatment plants. The waste material is taken to a waste dump.

Three plants are used for the treatment of the ore – a Heap Leach Facility, an Oxide Treatment Plant (OTP) and Sulphide Treatment Plant (STP). The treatment processes are similar to those presented in Figures 2.1 (Chapter 2), A1.1 and A1.2 (Appendix 1). AGC's heap leach process involves crushing of the ore (with ore grading averaging 1.5 g / t) from a stockpile to -25 mm, agglomerating the crushed ore with cement and barren solution and conveying it via radial stackers to heap leach pads. The pads are sprayed with dilute cyanide solution to leach the gold content. The 'pregnant' solution is pumped through carbon adsorption columns to remove the gold. The carbon is stripped by alcohol elution and the gold in solution electro-deposited onto steel wool cathodes and smelted to produce bullion. Treatment in the oxide plant is briefly described below:

Run-of-mine ore (with an average feed grade of 3.5 g / t) is crushed to -200 mm and conveyed to a mill operating in closed circuit with classifying hydrocyclones. Pulp from the milling and classification circuit is screened to remove trash and then directed to Carbon-In-Leach (CIL) tanks. Loaded carbon is stripped and the resulting gold solution electro-deposited and smelted to produce bullion. Tailings are pumped to an impoundment area (a tailings dam) from which reclaimed water is returned to the oxide plant for re-use.

Sulphide-hosted gold from AGC's surface mining operations in the Sansu area is treated by concentrate roasting at its plant located at Pompora near Obuasi (the Pompora Treatment Plant [PTP]). The plant recovers free gold by gravity concentration whilst refractory sulphide-hosted gold is recovered by a combination of gravity and froth flotation into a concentrate which is subsequently roasted to covert the sulphides into a form (the oxide form) suitable for cyanidation. The roasted concentrate (calcine) is then leached with cyanide and the dissolved gold recovered by the Merrill-Crowe process (see Figure A1.3 – Appendix 1). The gold concentrate is then smelted and precipitated to produce bullion.

5.2.2 *Positive Mining Impacts*

The main positive impacts of AGC's mining operations were found to be as follows:

i. *Employment*

AGC has been a major employer of labour in Ghana for many years. With a workforce of 10,000 people, the company is the country's largest single employer of labour. Senior Management number around 90 of whom only 30 are expatriates. In addition, AGC's main contractor, Mining and Buildings Contractors Ltd (MBC) employs about 600 Ghanaians. AGC also operates a hospital at Obuasi where 160 Ghanaians comprising a Medical Services Manager, 9 doctors, 137 nurses and 13 other staff (mainly labourers and auxiliary workers) are employed. Although AGC Management admitted that relatively few of the company's workforce are from the mining area itself, it maintained that all appointments were entirely on merit, and that it was rather unfortunate that very few 'local' residents had the requisite technical and managerial skills needed by a company that has to compete on the international market. This, notwithstanding, the company, as a policy, had always made every effort to recruit as many local people as possible for the less specialised or non-skilled jobs in the company.

ii. *Health Services*

AGC has a policy to treat anyone who goes to its hospital irrespective of whether they are connected with the company or not. AGC considers this policy as being very important in the view of the absence of satisfactory alternative facilities in a 40-mile radius. The hospital treats 18,000 – 19,000 outpatients per month of whom 10% are non-AGC staff. Although there are government Health Centres in Obuasi township and Akrokerri (a town 18 km from Obuasi), they provide limited health care, so most medical cases in the Adansi West District requiring specialist attention are usually referred to the AGC hospital at Obuasi.

iii. *Schools*

AGC, in the past, had assisted in the refurbishment of many schools in the Obuasi township, provided funds that helped put up school blocks for a village

(Jimisokakraba) and for the construction of a Primary School Complex for another village (Odumasi) in the mining area.

iv. *Community Projects / Social Amenities*

AGC-assisted community projects aimed at improving the socio-economic lives of communities in the Obuasi mining area had included:

- Periodic provision of funds (e.g. ¢250,000,000 in 1998) to the Adansi West District Assembly as the company's contribution towards the Assembly's Development Programmes in the district
- Procurement of low tension poles for rural electrification in some villages in the Obuasi area including Jacobu (300 poles), Old Ayaasi (40 poles), Jimisokakraba (40 poles) and Sansu (40 poles)
- Construction of a First-Class Football Stadium (Len-Clay Stadium) for Obuasi

5.2.3 ***Mitigation of Adverse Mining Impacts***

Measures employed to minimise the negative environmental and socio-economic impacts at the various stages of AGC's surface mining operations are described in the sub-sections below.

5.2.3.1 *Pre-Mining Stage*

Most of AGC's mining operations that took place before 1995 were undertaken without due regard for the environment. However, in recent mining activities –

notably, the Ashanti Mine Expansion Project (AMEP) in the Kubi area of its Obuasi gold concession – a number of environmental protection measures have been pursued.

In the 1999 Kubi project (AMEP) for instance, the following steps were taken to minimise adverse impacts at the pre-mining stage of the mineral development process:

i. *Baseline Studies*

Prior to the commencement of AGC's Kubi project (AMEP), comprehensive baseline studies were undertaken as part of the environmental management strategy pursued by the Environmental Management Department of the company. Table 5.2 summarises the baseline data collected. Where the specific method / technique employed in the acquisition of a particular set of data was made known, this has been stated.

ii. *Environmental Impact Assessment*

As a condition for the approval of the Ashanti Mine Expansion Project (AMEP) by the Environmental Protection Agency (EPA) of Ghana, AGC undertook an Environmental Impact Assessment (EIA) study of the project site and surroundings. Although details of the EIA study are not presented in this thesis, the fact that EPA eventually gave AGC an Environmental Permit to commence the AMEP in late 1999 gives an indication that EPA was satisfied with the quality of the assessment. It also suggests that the study covered all areas stipulated by EPA in its 'Ghana Environmental Impact Assessment Guidelines', a document that guides proponents on Impact Assessment studies and the preparation of Environmental Impact Statements.

Table 5.2 Baseline Data for EIA: Ashanti Mine Expansion Project (AMEP)

Baseline / Components ATMOSPHERIC ENVIRONMENT	METHODOLOGY / TECHNIQUE USED
Mean Monthly Rainfall Characteristics	Arithmetic Mean method used in estimating (rainfall) values obtained from Ghana Meteorological Services Department's (GMSD's) Dunkwa-On-Offin weather station (records from 1991 – 1998)
Mean Monthly Air Temperature	Arithmetic Mean method used in estimating (temperature) values obtained from GMSD's Dunkwa-On-Offin weather station (records from 1991 – 1998)
Relative Humidity (R.H.)	Mean monthly R.H. estimated from values obtained from GMSD's Dunkwa-On-Offin weather station (records from 1991 – 1998)
Evaporation	Mean annual pan evaporation rate estimated from values recorded by AGC at Obuasi from 1995 – 1998
Air Quality	Simultaneous collection of samples of particulates of Dust and As_2O_3, and SO_2 for a 10-day period (in June 1998) using an SKC Universal Flow Sampling Pump (Model 224-PCX R8): Total mass of particulate matter (dust) was determined gravimetrically; Arsenic concentrations were determined using the Hydride Generation method; Sulphur Dioxide concentrations were determined by 'Sulphate Analysis' using Ion Chromatograph

Table 5.2 Ctd.	
WATER ENVIRONMENT	METHODOLOGY / TECHNIQUE USED
Uses of Rivers / Streams	Observation / interview of local communities
Mean Monthly River / Stream Flows	Estimated from flow values (1991– 1998) obtained for River Ofin by the Water Resources Research Institute (WRRI) of Ghana
Flood magnitude & frequencies	Obtained by AGC after studying flood events in the Obuasi area from 1996 to 1998 and using the U.S. Soil Conservation Synthetic Hydrograph method to calculate the flood magnitude and frequencies
Water Quality (physical & chemical / bacteriological parameters)	Sampling and analysis of water from 3 sampling points – Upstream, Middle and Downstream sections of major rivers / streams in the concession – in June 1998: *Physical Parameters investigated – pH, Conductivity, Total Suspended Solids & Total Dissolved Solids (+) *Chemical / Bacteriological parameters investigated – Concentrations of free CN^-, soluble As, Fe, Zn, Cu, Pb, Mg and Cl^-, and Faecal & Total Coliforms (++)
Uses of Groundwater	Observation / interview of local communities
Groundwater Quality (chemical / bacteriological parameters)	Water samples from open wells in 5 villages in the mining area were analysed for all the physical and chemical / bacteriological parameters mentioned above (+/ ++)

Table 5.2 Ctd.	
GEOLOGY	METHODOLOGY / TECHNIQUE USED
–	Analysis of rock samples from various sections of the concession for their geological attributes, guided by previous description of the geology of the area by Kesse (1985)
SOILS	METHODOLOGY / TECHNIQUE USED
- Soil developed on Tarkwain Rock - Soil developed on Birimian Rock	*Examination / Analysis of representative soil samples from auger / chisel bores and exploration pits and detailed description of the soils using the Food and Agricultural Organisation (FAO) method (FAO, 1990a); using their inherent properties, the soils were then classified according to the Revised Legend of the Soil Map of the World (FAO, 1990b) *The soils were also evaluated for their suitability for agricultural production according to FAO (1976)
FLORA	METHODOLOGY / TECHNIQUE USED
Vegetation – general	Literature – earlier classification by Taylor (1960) used
Vegetation Units	*A random sampling method based on a modified version of Mueller-Dombois & Ellenberg (1974) *Species identification was based on Hutchinson & Dalziel (1956)

Table 5.2 Ctd.	
FAUNA	METHODOLOGY / TECHNIQUE USED
- Large Mammals - Rodents and Bats - Birds - Herpetofauna	*Direct observation, interview of local residents (including hunters & bush meat sellers) and sampling / fauna identification in five study sites after Meester & Setzer (1971) [for mammal identification]; Rosevear (1969) [for rodent identification]; Rosevear (1965) [for bat identification]; Keith *et al* (1992) [for bird identification]; the presence of Herpetofauna (amphibia and reptiles) was ascertained mainly through observation and discussions with local people
SOCIO-ECONOMIC BASELINE	METHODOLOGY / TECHNIQUE USED
- Population and Culture - Local Economy and Employment - Education - Water & Env'tal Sanitation - Land use	Mainly through field observations (in the various villages in the mining area and surroundings), by interviewing representative samples of the local communities and using statistical and other forms of data obtained from the following public and private institutions: *Amansie West District Assembly *Statistical Services Department *Land Valuation Board *Ghana Water Company Limited (GWCL) *Town & Country Planning Department *Economic Planning Department *Ghana Education Service *Traditional Councils *National Board for Small Scale Industries (NBSSI) *Association of Small Scale Industries

iii. *Consultations / Community Concerns*

Consultations – most of which centred on environmental protection issues – were held with appropriate government institutions (including the Mines Department, EPA, Minerals Commission, Forestry Service and the Ghana Highway Authority) prior to the commencement of the AMEP. Community leaders, landowners and other 'important' members of local communities were also consulted to help identify and make informed decisions on how environmental and socio-economic issues of concern should be addressed at both the constructional and operational phases of the project. A series of public consultations were held with local residents, traditional and civil authorities in the project area to discuss the likely impacts – both positive and negative – of the project. Again, in conjunction with personnel of the EPA, a public hearing was organised where local concerns were raised and discussed. Following these consultations, the following measures were taken among others:

- AGC undertook a comprehensive inventory of land and other property that were likely to be affected by the project, and affected individuals paid compensations before the commencement of active mining
- The company carried out infrastructural developments aimed at improving the standard of living of rural communities in the project area including (i), upgrading some access roads in the area, and (ii), providing a by-pass road north of the Kubi Kwanto village to reduce disturbance and interference by mine vehicles
- AGC recruited as many local community members as possible for non-skilled work at the new mine

iv. *Planning*

The following were among the impact mitigation measures taken by AGC during the Planning Stage of the Ashanti Mine Expansion Project:

- Baseline data over a 17-year period were used in the design and siting of settlement ponds / sumps at the mine – from an analysis of 2161 daily storm events in the area, rainfall events in excess of 100 mm day^{-1} over the 17-year period were ascertained. Then, given the average rainfall duration in the area of 2 –3 hours and using a worse-case scenario of 1 in 17 year peak rainfall of 100 mm day^{-1}, the volume of water expected to be generated in the event of a flash rain of about 3-hour duration was estimated. This fact was then made use of in the design of sumps to accommodate the estimated volume of water
- To minimise runoff and sediment loading in streams, flat, open areas were earmarked for the construction of sites for ore stockpiling and dumping of waste (including tailings). Again, to minimise siltation and pollution of streams, waste dumps and ore stockpiles were located away from existing drainage systems
- Evaluation of metallurgical options for a sulphide plant for the AMEP included the cost of pollution control technology – in view of the potential environmental damage associated with the discharge of gaseous sulphur dioxide and airborne arsenic trioxide wastes, the design of the proposed Sulphur Treatment Plant included appropriate technologies to minimise adverse environmental impacts. Both pyrometallurgical (concentrate and whole ore roasting) and hydrometallurgical (concentrate biological and concentrate pressure oxidation) measures were considered. The flow sheets of both processes included

provision for the capture and disposal of As_2O_3 from roasting. The cost of removing SO_2 by scrubbing was also included in the financial analysis. After a careful evaluation of the above options, the Concentrated Biological Oxidation (CBO) process was adopted by AGC. In this process, arsenic in solution is stabilised as ferric arsenate precipitate and fed to a tailings dam for disposal. Again, sulphur is converted to ferric sulphate and sulphuric acid, which is neutralised with lime before being discharged to the tailings dam

5.2.3.2 *Exploration*

Steps taken by AGC to reduce adverse impacts associated with the exploration phase of the Sansu Mine and the Kubi Mine (under the Ashanti Mine Expansion Project) included the following:

- The use of manual trenching to minimise destruction of vegetal cover
- Holes and trenches were backfilled on completion of exploration
- Barricades were erected in areas downslope of trenches, to minimise pollution of rivers / streams with boulders and debris
- Sampling was generally carried out away from rivers and streams
- As much as possible, drilling and trenching were undertaken in low-lying areas to avoid deep excavation by bulldozing
- Sampling and drilling works were generally planned away from wet areas
- Bulk sample rejects were placed in large plastic bags and transported to a well-protected core and bagging shed for safe disposal later

5.2.3.3 *Site Preparation / Mineral Extraction*

Steps taken by AGC to reduce the impact of site preparation and mineral extraction during the operational phase of the Sansu and Kubi mines had included the following precautionary and preventative measures:

- Where sites were prepared on hilly terrain, utmost care had been taken to bench and barricade the sites to prevent excavations moving into water courses
- To reduce adverse impacts associated with blasting activities, AGC had moved away from the Cortex-Top-The Hole Initiation System of blasting to the Nonel-Down-The Hole system, with: (i), single hole initiation and delays between charges; (ii), trials carried out to redesign charge per blast; (iii), blast holes covered with appropriate material to avoid flyrock; and (iv), stemming (use of chippings) to reduce noise
- The use of water sprays and dust-suppression chemicals, and, use of mufflers on vehicles, to reduce dust pollution
- Stockpiling of topsoil for use in future revegetation programmes

5.2.3.4 *Beneficiation, Gold Recovery / Bullion Production*

The following measures had been put in place to reduce the adverse impacts associated with this phase of AGC's mining activities in the Obuasi area:

i. *Waste Minimisation / Management*

In pursuit of its policy of preventing the creation of pollution or nuisance at source rather than subsequently trying to counteract the effects thereof, AGC had explored a number of waste minimisation options. For instance, in the implementation of the Ashanti Mine Expansion Project, having initially identified potential pollutants of the metallurgical processes as Sulphur Dioxide (SO_2) and Arsenic Trioxide (As_2O_3), full consideration was given to the elimination of these two pollutants within each process route. This was to ensure that SO_2 and As_2O_3 were not emitted into the atmosphere, and that As_2O_3 concentrations in liquid effluents were not above internationally accepted levels or Ghana EPA permissible levels. To bring this about, the Concentrated Biological Oxidation (CBO) ore processing technique was adopted (see section 5.2.3.2 [iv]).

ii. *Employment of 'Cleaner' Waste Disposal Techniques*

AGC had resorted to the use of 'cleaner' waste disposal techniques and the use of an 'Integrated pollution Control' approach in minimising most of the environmental problems associated with its operations. For instance, after realising that the major primary source of atmospheric pollution in the Obuasi area was the stack of the Pompora Sulphide Treatment Plant – which during the ore roasting process had been emitting arsenic in particulate form (As_2O_3) – an As_2O_3 control device (Arsenic Removal Plant [ARP]) was installed to reduce As_2O_3 emissions to acceptable levels. The ARP is a cooling and filtering system (consisting of cells each containing 153 filter bags) that uses a 'bag-house' filter technology. It was disclosed during the field survey that following the installation of the ARP, results of ambient air arsenic concentrations for the Obuasi area were within Ghana EPA /

World Bank environmental guideline of 3.0 $\mu g /m^3$. There was also a pecuniary benefit – recovered arsenic material was being sold to an overseas purchaser in France (Metaleurop) to generate funds for AGC. In addition to the ARP, the design of the sulphide treatment plant incorporated a provision for the future inclusion of a sulphur dioxide scrubber if necessary, i.e., if monitoring of ground level concentrations of sulphur dioxide showed that guideline levels were being exceeded.

iii. *Dust Control*

To reduce dust pollution – especially during the principal dry season from November to February – AGC had put in place a number of dust control measures. These measures included fixing a Dust Extractor at the Sansu Oxide Plant's comminution circuit, a water spray at the Pompora Sulphide Treatment Plant's crushing unit, and regular spraying of roads by water bowsers. Dust suppression trials using a chemical suppressant (Coherex) had also been carried out and found to be very effective in suppressing dust.

iv. *Use of Appropriate Recycling / Re-use Strategies*

In their effort to reduce the need for fresh raw materials, make effluent control easier, reduce pollution substantially and save reagent and pumping power requirements, AGC had been employing various recycling / reuse, and waste treatment / disposal techniques as follows:

(a) The design of AGC's Heap leach process was based on the principle of 'self containment', i.e., under normal operating and weather conditions, there should be no discharge of effluent into the environment. The system has been designed in such a way that cyanide-bearing solutions are totally self-contained within the circuit of heap leach pads, solution holding ponds and the gold recovery plant, where used process solutions are eventually recycled and reused. Again, overflow ponds connected to the heap leach process site had been designed such that they will overflow only after heavy rainfall of an intensity which is expected, on the average, to occur only once in every 10 years. Even here, provision had been made to neutralise the excess solution in a neutralising pond by alkaline chlorination before being discharged into the environment.

(b) The risk of seepage of cyanide-bearing solution into the underlying ground had been reduced by underlying the pads with heavy HDPE membrane, over compacted soil. As an additional precaution, a leak detection system had been installed beneath the ponds.

(c) The company's Oxide Treatment Plant had been designed to contain all the process waste water – seepage ponds besides the process tailings dam collect seepage flows from the dam, and clarified water from the dam recycled for use in the processing plant. The dam was designed to be capable, if properly managed, of containing a 1 in 100 year rainfall event without overflowing, with the expectation that there would be no overflow from the dam into the environment under normal operating and weather conditions.

(d) In order to reduce the effect of discharges from the tailings dam into the environment (especially, where there is the need to discharge excess water from the dam into local streams to ensure dam stability), guidelines for discharges had been developed. For instance, the Oxide Plant Management is required to give the Environmental Management Department at least a 48-hour notice before any planned discharge, which can be effected only after approval has been granted by the Environmental Management Department.

v. *Waste / Runoff Water Management*

Steps that had been taken to minimise the effects of waste / runoff water included the following:

- Construction of toe drains around tailings dams with contents of the toe drains eventually reporting to seepage collection dumps for pumping back to tailings dams
- Construction of settling ponds (lined with HDPE material) and silt traps downslope of waste dump sites to collect runoff from waste dump areas
- Construction of a system of drains ending in silt traps, to collect runoff from general mining area
- Use of compacted laterite in the construction of basement of tailings dams to minimise seepage of waste water / leachates

vi. *Mitigation of socio-economic impacts*

The following measures had been taken by AGC to reduce the socio-economic impacts of this phase of mining:

- Alternative sources of water supply (mainly boreholes) had been provided to communities whose traditional sources of water (rivers / streams) had been rendered unsuitable for drinking and other domestic use as a result of mining activites – as at the end of 1999, AGC had provided over 70 boreholes fitted with pumps as alternatives to rivers and streams for communities downstream of its operations at a cost of over $ 600,000

- To reduce social problems associated with noise, vibrations and flyrocks, AGC had moved from the previously used Cordex-Top-The Hole initiation system of blasting to the Nonel-Down-The Hole initiation system. This had resulted in improved blast efficiency, less air overpressure and a reduction in the incidence of flyrock. Adverse blasting impacts had been further reduced by restricting blasting requirement as much as possible, by the careful design and accurate implementation of drilling and blasting procedures, under the supervision of an experienced and accredited blasting engineer
- In extreme cases, whole communities had been relocated / resettled – for instance, in 1996, due to its proximity to mining operation sites, especially, the flyrock zone, an entire village (Bidiem) was relocated by AGC at a cost of over $1,000,000. A suitable site for the resettlement of the people of Bidiem acceptable to all stakeholders was located at Nyamso, about 5 km from Obuasi. The project consisted of the construction of 101 houses, access roads, a church, a fetish grove, 2 boreholes with hand pumps, 2 Ventilated Improved Pit (VIP) toilets and a palace

vii. *Revegetation , Erosion Control & Minimisation of Sedimentation*

To minimise environmental degradation in the mining area and surroundings, the following steps had been taken by AGC among others:

- Revegetation works had been commenced in the 'Bald Hill' area near Obuasi (a vast area covered with defoliated trees as a result of SO_2 and As_2O_3 pollution –

as at the end of 1999, 130,000 seedlings of *Leucaena leucocephala* and clumps of *Vetiveria zizanioides* grass had been planted on the 'Bald Hill'

- To help check erosion, several deep gullies had been planted to *Vetiveria zizanioides* and *Brachialla* grasses. Other erosion control strategies had included the construction of trenches each measuring 0.6 x 1.5 x 1.2 m deep as silt traps, collecting sediment-bearing runoff to check erosion and reduce sedimentation in rivers / streams. Again, *Leucaena leucocephala* and *Brachialla* grass had been planted along the side walls of the Kokoteasua East and Sansu tailings dams to help stabilise the dams

viii. *Monitoring*

While monitoring of air quality in the Obuasi area by AGC dates back to 1994, the company commenced active monitoring of water quality in the area in 1998, following EPA's directive in late 1997 that all large-scale mining companies in Ghana should monitor and report on the environmental quality of their mining area. While air quality monitoring had been concentrated on measurement of ground level concentrations of dust particulates, As_2O_3 and SO_2, water quality monitoring had focused on measurement of pH, Conductivity, Total Suspended Solids and concentrations of Arsenic, Cyanide, Iron and Lead (see Tables A14. 1 – 7: Appendix 14). Water sampling locations (Figure 5.1) had been chosen after a careful study of pollution sources and sinks (receptors). Systematic measurement of ground level concentrations of dust particulates, As_2O_3 and SO_2 had been carried out after obtaining samples simultaneously using an SKC Universal Flow Sampling Pump (Model 224-PCX R8). Results obtained – which were not made

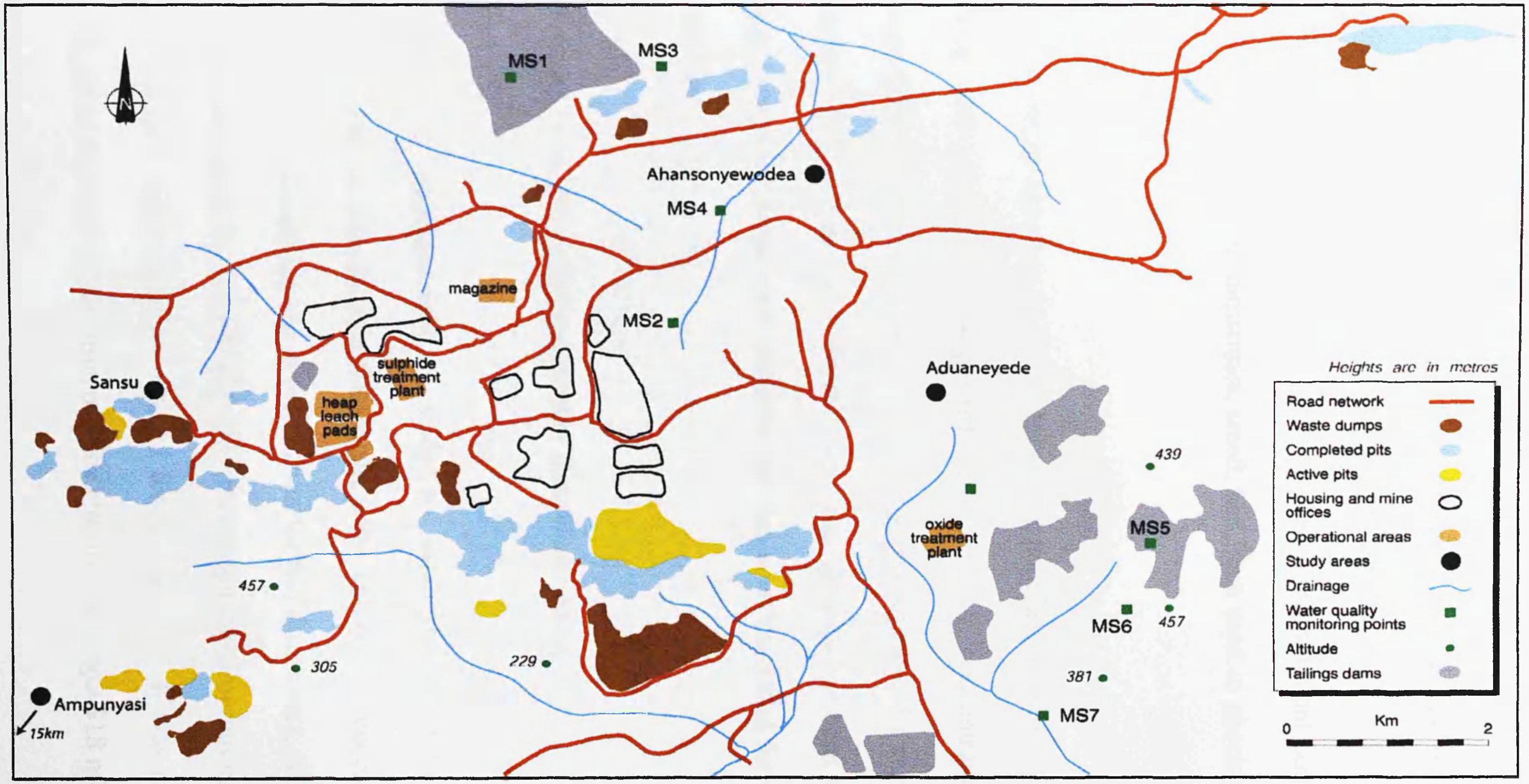

Figure 5.1: Map showing AGC's Water Quality Monitoring Sites (Derived from AGC's Mine Plan and Ghana Topographical Map [Sheet] No. 062C1

available for examination – had then been compared with Ghana EPA's guideline values ($3\mu g/m^3$ for As_2O_3; $80\mu g/m^3$ for SO_2 and $100\mu g/m^3$ for dust particulates). In addition to using scientific equipment to obtain and analyse air and water samples, physical monitoring such as checks for vegetation damage, smell and visible smoke had also been used to identify areas with high airborne pollutant concentrations, while colour, turbidity and sometimes, smell, had been used to check pollution in rivers and streams.

Most of the 10 air samplers had been located at population centres where initial modelling and observations suggested possible high concentrations of air pollutants. Other monitoring programmes in the past had included a survey of trace elements in mine workers and local residents – hair samples had been analysed for arsenic and other elements while subjects had also been examined for exposure to these elements.

5.2.3.5 *Post-Mining Phase: Mine Closure / Decommissioning*

In 1996, AGC commissioned a study to establish the future cost of decommissioning its operations in the Obuasi area. The cost of decommissioning was estimated at $18 million and in preparation for this future cost, AGC has been making financial provision ahead of the decommissioning programme. As at the end of 1999, $5.2 million had been saved for this purpose. It was reported that given the life of the mine, by the time of mine closure, the target $18 million would have been raised.

After cessation of mining operations, AGC has plans to return the entire area around Obuasi occupied by its mining operations to rural communities in the area, in a state suitable for one form of land use or another. To achieve this, AGC had taken the following measures among others:

- A Revegetation Action Plan had been developed, with provision for a full-time Revegetation Officer to see to its implementation – execution of the plan will see the revegetation of old working areas such as the denuded hills in the Pompora and Kokoteasua valleys, inactive tailings dams, as well as the present open pits and tailings dams (in the Ashanti Mine Expansion Project) when they become inactive
- Two nurseries – with a combined capacity to produce 2 million container-grown seedlings per year – had been established. A pilot revegetation programme had already been commenced, with more than a million trees planted in some mined-out areas
- A 3-year Reclamation Plan (March 2000 – December 2003) had been developed for all mined-out areas within the Obuasi concession. The ultimate aim of the plan is to reclaim and / or rehabilitate all mined-out areas into forms suitable for forestry plantations, agricultural development, fish farming and urban green space areas. The Reclamation plan encompasses design and engineering aspects of landscaping and slope stability, revegetation trials and the scheduling of earthmoving activities
- A 'Post-Mining' Environmental Management Plan had been prepared with a number of measures spelt out including (i), the creation of landforms which are

compatible with adjacent landscape to minimise long term visual impacts, (ii), discussions with rural community leaders aimed at handing most of the structures that remain as permanent features on the mine sites to them, to be used as communal facilities, and (iii), monitoring for AMD by regular inspections of stockpile and waste dump areas, streams downstream of open pits and waste dumps, and regular measurement of pH of representative samples taken from these areas

5.3 **Resolute Amansie Limited (RAL)**

RAL commenced surface mining operations in the Amansie West District of the Ashanti Region of Ghana in 1996. It was ascertained during the field survey that adverse impacts created by RAL's mining operations were being tackled through the implementation of well-planned environmental management programmes including strategies to reduce adverse socio-economic impacts of mining operations. In the sections below, RAL's gold mining and processing methods are described and the positive impacts created by their mining activities outlined. Measures put in place to minimise adverse impacts of the company's activities are also presented.

5.3.1 ***Mining and Ore Processing***

Open-pit mining methods are used for ore extraction at the RAL's Manso-Nkran gold mine and the extracted ore processed in a Carbon-in-Leach (CIL) processing plant. A simplified ore treatment flowsheet at the mine is shown in Figure 5.2.

The extracted ore (mainly oxide ore from the Nkran Pit) is dumped on a Run-Of-Mine (ROM) stockpile or fed directly to a single stage crusher. Crushed ore is fed to a Semi-Autogenous Grinding (SAG) mill, which partially feeds into a gravity concentrator. Grinding is facilitated in the SAG mill by the addition of lime in a Semi-Autogenous Grinding (SAG) mill, which partially feeds into a gravity return water (from the mine tailings dam). A slurry of finely ground material exiting the SAG mill then enters a leach circuit where sodium cyanide is added. After leaching, the gold is removed on activated carbon before elution, electrowinning and bullion production in the gold room, as previously described (see Figure 2.1 – Chapter 2). After the gold has been extracted, the barren slurry of finely ground material is pumped to the tailings dam. Ore processing water is sourced from a raw water dam and water recycled from the mine tailings dam using a decant pump. Additional water is obtained by dewatering bores around the mine.

5.3.2 *Positive Mining impacts*

The following were the key positive impacts found to be associated with RAL's mining operations in the Manso-Nkran area:

i. *Employment*

RAL had employed 15% of its workforce from the Manso-Nkran (mining) area who were being paid an average amount of ¢20 million per month. Added to this was an injection of almost ¢40 million per month into the local economy through indirect employment such as casual labour contracts for planting of grass, local

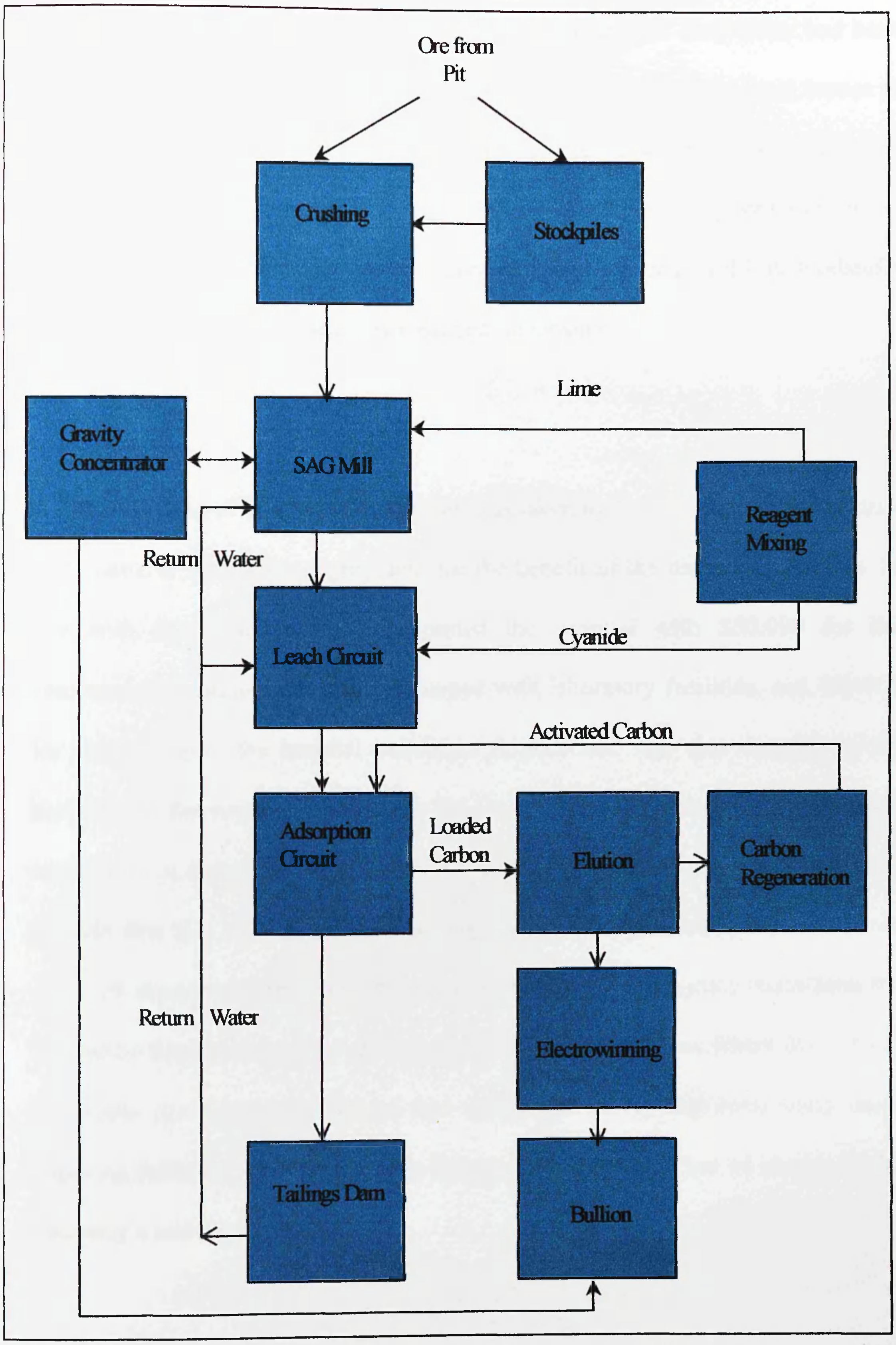

Figure 5.2: A Simplified Flowsheet for RAL's Oxide Ore Processing

carpentry, tailoring and supply of foodstuffs. For instance, a local tailor had been commissioned to produce all staff uniforms. The most significant indirect source of income to local residents was mentioned as renting of accommodation to mine workers. About 400 workers employed from outside the mining area stay in the local villages from Manso-Nkran to Agroyesum and pay rent and buy foodstuffs and other essentials from local landlords and merchants.

ii. *Health*

At the beginning of the project, a decision was taken by RAL to support the District (St. Martin's) Hospital at Agroyesum for the benefit of the district as a whole. In line with this decision, RAL supported the hospital with $50,000 for the construction of an x-ray building equipped with laboratory facilities, and $60,000 for the wiring of the hospital buildings. A generator was also donated to the hospital for the supply of electricity for its operations. A small clinic was also established at the mine site and staffed with a medical officer and 4 nurses to provide first aid, medical care and emergency assistance to company employees and their dependants. However, by reason of proximity, emergency cases from the immediate local communities are brought to the mine site clinic where they (about 30 people per month) are treated free of charge. Emergency community cases requiring referral to the St. Martin's Hospital are conveyed free of charge in the company's ambulance.

iii. *Water & Sanitation*

RAL had provided good drinking water and places of convenience to:

- The immediate communities around the mine because of the potential for their water sources to be affected by mining activities and the lack of hygienic places of convenience in those communities prior to the commencement of mining operations
- Communities with company employees living in them, to reduce the impact of the increase in population on those facilities
- Other communities in the mining area found to be lacking or in dire need of clean source of drinking water and / or hygienic places of convenience

Nine communities (Koninase, Kwanchiabo, Nkran, Dadease, Agroyesum, Adubia, Afedia, Odumasi and Adubiaso) had benefited from boreholes and / or places of convenience (Ventilated Improved Pits – VIP's) at a total cost to the company of \$166 million (¢332 million). Again, two hand-dug wells had been donated to the Manso-Nkwanta Articulated Water Project (AWP) for use by farmers in the northern part of the mine tailings dam.

iv. *Road Improvement & Maintenance*

Prior to the mine coming to the Manso-Nkran area, the roads in the area were in very poor condition. Most of them were regraded or repaired at the inception of mining. The development of the mine also meant that certain roads had to be closed and rebuilt in another location around the mine. When this was done, the newly built roads were an improvement over the old roads. There had also been the need for ongoing maintenance of existing roads by the company due to lack of resources by the Feeder Roads Department to do this. As at the end of 1999, \$281,500 had been spent on road maintenance and improvement in the mining area including:

- Road upgrade from Poano to Mim Junction, and from Mim Junction to Manso-Nkran
- Construction of an alternative road from Manso-Nkwanta to Kwanchiabo
- Construction of a bridge near Kwanchiabo to facilitate access of commercial vehicles to the village
- Expansion of the Manso-Nkran – Nkuntin road to make it safer for use by trucks and buses

v. *Sustainable Livelihood through Agriculture*

To improve the economic welfare of communities in RAL's mining area, the company established an agriculture-based Sustainable Livelihood Project (SLP) for the communities in 1998. The main objective of the project was to facilitate the development of commercial agriculture rather than subsistence farming in the area around the mine. This was to be achieved through establishing a means for micro-financing and technical support for the farmers. The SLP started with seven staff (including an Agric / Agroforestry expert and a Project Co-ordinator). Interested farmers – about 300 in all – were registered into co-operative groups and trained on improved farming / agroforestry practices. They were afterwards provided with seedlings of selected tree species (mainly multi-purpose trees) and crops (including oil palm and cola) raised at the project nursery. They were then provided with farm equipment and financial input (¢800,000 per farmer) to commence farming activities. As at the end of 1999, 272 out of the 300 registered farmers had reported substantial improvement in their socio-economic lives as a result of the project.

vi. *Education*

Under its Educational Facilities Improvement Programme (EFIP), RAL had supplied building materials to needy communities for the construction of new schools and rehabilitation of existing ones. In 1998, RAL joined hands with the Amansie West District Assembly in the construction of a Model Primary School and Teachers' Living Quarters. As at the end of 1999, beneficiaries of RAL's EFIP had included:

- Nkran / Koninase – a model primary school consisting of 6 classrooms, an office and a store room, and, 6 units of teachers' accommodation
- Kaniago – given $3,000 worth of building materials for the renovation of a primary school
- Dadease – given $5,000 worth of building materials for the construction of a kindergarten building
- Kwanchiabo – given $5,000 worth of building materials for the construction of a kindergarten building

vii. *Community Projects / Social Welfare*

RAL had supported communities in their mining area in the following ways:

- Donation of $7,500 towards the construction of a market at Manso-Nkran
- Yearly donation of $800 - $1,000 towards the celebration of District Farmers' Day by the Amansie West District Assembly

- Purchase of 60 teak poles each for Nkran, Koninase, Dadease and Kwanchiabo as RAL's contribution towards the Amansie West District Assembly's Rural Electrification Project in the four communities
- A yearly (Christmas) donation of about $6,000 to the Traditional Councils in the mining area and miscellaneous donations to patients and staff of the District (St. Martin's) Hospital at Agroyesum

5.3.3 *Mitigation of Adverse Mining Impacts*

Measures employed to minimise adverse impacts at the various stages of RAL's mining operations are described below.

5.3.3.1 *Pre-Mining Stage*

Environmental protection / management measures taken during the pre-mining stage of RAL's mining operations in the Manso-Nkran area included the following:

i. *Baseline studies*

To help understand the characteristics of the pre-mining environment for effective environmental planning / management, RAL undertook baseline studies in their Manso-Nkran mining concession and surroundings including a 14-month ambient air and water quality studies) before commencing active mining operations in the area. Table 5.3 summarises the baseline data collected. It must be stated that for

Table 5.3: Baseline Data for EIA: RAL's Manso-Nkran Gold Mining Project

BASELINE / COMPONENTS ATMOSPHERIC ENVIRONMENT	METHODOLOGY / TECHNIQUE USED
Mean Monthly Rainfall	Arithmetic Mean Method used in estimating (rainfall) values obtained from Ghana Meteorological Service Departments (GMSD's) Ashanti Bekwai Weather Station (records from 1961 – 1991)
Mean Monthly Air Temperature	Arithmetic Mean Method used in estimating (temperature) values from GMSD's Kumasi Weather Station (from 1939 – 1992)
Relative Humidity (R.H.)	Mean Monthly R.H. obtained from GMSD's Ashanti Bekwai Weather Station (records from 1961 – 1991)
Air Quality	Representative samples of air analysed for dust and sulphur dioxide concentrations

Table 5.3 Ctd.

WATER ENVIRONMENT	METHODOLOGY / TECHNIQUE USED
Drainage Pattern	-
Uses of Rivers / Streams & Groundwater	Observations / Interview of local communities
Mean Monthly River / Stream Flow	Estimated from 5-year flow values (1985 – 1990) from nearest gauged river (River Ofin) by the WRRI
Surface Water Quality	Surface water samples were collected from the main rivers draining the project area (the Ayensu Creek and Rivers Ofin, Adubia, Subin and Kanango) – the samples were then analysed for concentrations of Hg, Cd, Pb, As, Cu, Cr, Zn, Ni, Mn and Fe, as well as PO_4-P, NH_3-N, BOD, COD and CN^-
Groundwater Quality	Water samples from a well in one village (Akwasiso) and boreholes in three villages (Kumpese, Dome-Kaniago and Manso-Nkran) near the concession were analysed for pH, Conductivity, Turbidity, DO, TSS, and Hardness, as well as concentrations of Na, K, Ca, HCO_3^-, Cl^- and SO_4^{2-}
Aquifer Characteristics	-
Evapotranspiration	Mean Daily Evapotranspiration values estimated from evaporation data obtained from a Class A Pan in Kumasi for a 4-year period (1987 – 1991)

Table 5.3 Ctd.	
GEOLOGY	METHODOLOGY / TECHNIQUE USED
-	Analysis of rock samples from various sections of the concession for geological information by a team led by the Senior Mine Geologist
SOILS	*Soil samples from 'borehole logs' from various sections of the concession were obtained, taking adequate care to separate the various profiles *The soil samples were air-dried, ground and sieved through 2 mm mesh. 200g of each sample was then weighed and used for physical analysis including depth, lithology, pH, Natural Moisture Content and percentage of clay, silt, sand and gravel
FLORA	METHODOLOGY / TECHNIQUE USED
Vegetation – general	Literature – earlier classification by Hall & Swaine (1981) used
- Vegetation Units - Diversity of Flora - Conservation Significance of floral species	*A visual appraisal of the types of vegetation zones in the concession area was done prior to establishing areas for investigation *Using Random sampling and Line Transect methods, 4 areas within the concession were selected and in each of the 4 areas, three 25m x 25m plots mapped out. The vegetation units, conservation significance and diversity of the flora in each plot were then studied and recorded

Table 5.3 Ctd.

FAUNA	METHODOLOGY / TECHNIQUE USED
- Rodents & Small Mammals - Bats & Birds - Large Mammals - Herpatofauna	*Two areas were selected within the concession – one in an abandoned farmland and the other in an advanced secondary forest – and information on faunal species encountered recorded *Rodents and small mammals were studied after capturing them using 25 baited Sherman's Live Traps. Trapping lasted two nights; examination and identification of trapped animals was done the following day *Bats and birds were trapped using two standard 12m long mist nets (2.6m high). These were erected on poles in each of the study sites for two nights (for bats) and two days (for birds). Bird species were further recorded by walking along randomly selected trails in the vicinity of the trapping area and other parts of the concession, and identifying their presence by visual observation or identification of their calls *Information on large mammals was obtained by direct observation and by examination of their spoors along trails in various parts of the concession area during the day and at dawn and dusk for 5 days. Additional information was obtained by interviewing hunters, bush meat sellers and 'chop bar' (local restaurant) operators in the villages of Manso-Nkran, Koninase, Kumpese, Adubea and Kaniago *Information on herpatofauna was obtained by direct observation and through discussions with local inhabitants

Table 5.3 Ctd.	
SOCIO-ECONOMIC BASELINE	METHODOLOGY / TECHNIQUE USED
- Ethnography & Population - Amenities: Roads, power supply and housing - Local Economy and employment, Water supply, Communication and Educational facilities - Health Profile: Population and housing, food and nutrition, sanitary waste management, health facilities and infrastructure, common diseases and diseases of public health concern - Land Use	*The Chiefs and Elders of the villages in the mining area were consulted on matters of water supply, health, employment, diseases and social welfare *The regional clinics were requested to provide historical data relating to health disorders and other health-related complaints from the local communities *Other socio-economic information was obtained from the following public institutions: - Department of Survey - Forestry Service - Statistical Services Department - Town & Country Planning Department - Ghana Education Service - Amansie West District Assembly - Ministry of Food & Agriculture - Ghana Water Company Limited - Economic Planning Department - Department of Social Welfare

some of the baseline data collected by RAL, the specific methodologies / techniques employed in acquiring them were either not made available or were considered too inadequate for presentation in this thesis. Where the specific methodology / technique used was given in reasonable detail however, this has been stated.

ii. *Environmental Impact Assessment*

In line with section 12 (1) of the Ghana Environmental Protection Agency Act 1994 (Act 490), RAL undertook an EIA study of its Manso-Nkran concession and its environs in February 1995. After a review of the Environmental Impact Statement (EIS) on the EIA study by EPA (Ghana), an environmental permit was eventually granted for RAL to commence mining operations in February 1996. This goes to suggest that EPA was satisfied with the quality of RAL's EIA study, especially, adverse impacts identified and provisions made for their mitigation.

iii. *Consultations / Community Concerns*

Prior to the commencement of the Manso-Nkran gold mining project, RAL consulted with a number of government departments (including the Environmental Protection Agency, the Mines Department, the Forestry Service, the Ghana Wildlife Service and the Ghana Water Company Limited) with a view to ascertaining environmental protection issues that needed addressing while implementing the project. Discussions were also held with members of the mining area community (including chiefs and elders of nearby communities, community opinion leaders and chief farmers) to find out community concerns that would need to be addressed while executing the project.

Following the above consultations, RAL undertook the following impact-mitigation measures among others:

- Agricultural land and other property likely to be affected by mining activities were made to be evaluated by the Land Valuation Board of Ghana and the owners appropriately compensated
- Management decided to employ at least 15% of the company's workforce from communities in the mining area
- RAL established a Training Scheme (in Agroforestry and other sound farming practices) and a 'flexible' Credit Facility that would eventually assist farmers to embark on commercial farming ventures both within and outside the company's concession
- Several roads linking villages in the mining area were upgraded or regraded
- A decision was made to provide sufficient potable water to all communities whose water sources (rivers / streams) were likely to be affected by mining operations

iv. *Planning*

The following were among the impact mitigation measures taken by RAL during the planning stage of its Manso-Nkran mining project:

- Provision was made for environmental protection within the initial operating budget – it was decided that ¢100 per every tonne of ore processed be saved and the accumulated amount eventually used for environmental protection and mitigation of adverse mining impacts

- Site testing was carried out to establish the potential for Acid Mine Drainage (AMD) from waste rock – this included measuring the pH of ground water in the area containing the ore deposit, and a small-scale site heap leach test
- Waste dumps were earmarked to be sited as close as possible to the proposed site for the open-cast pit, to minimise dumping distance and hence the amount of dust and noise typically associated with long waste-dumping distances
- It was decided that both high- and low-grade ore stockpile sites be located just adjacent to the plant site to ensure minimum impact on the available active area remaining between the processing plant and the mine pit
- The mine tailings dam was designed to be able to contain all tailings without the need to construct additional dams. The embankment was constructed of chemically stable material under the supervision of an independent geotechnical consultant. A spillway was included in the design, with return periods for extreme rainfall events of 50 years as the design criteria
- The mine tailings dam was located downstream of areas prone to increased runoff to ensure that all waste water from the mine site would be directed into the tailings dam. Again, the dam was strategically located within the Ayensu Creek catchment to ensure it was as close to the processing plant and mine pit as possible. This was also to provide the added advantage of having all project facilities within a single catchment and therefore confining environmental impacts to that catchment, for ease of their (environmental impacts) management

5.3.3.2 *Exploration*

Steps taken by RAL to minimise the adverse impacts of the exploration phase of its Manso-Nkran surface gold mining project included the following:

- Consultations were held with local chiefs and elders ahead of the exploration programme to ensure sites of cultural or spiritual significance were identified and efforts made to preserve them
- Efforts were made to locate and make use of as many existing tracks as possible to minimise clearance of vegetation to provide access to sites for exploration activities
- Manual trenching was used, to minimise destruction of vegetal cover and faunal habitats
- Generally, costeaning was carried out at least 30m away from the nearest river / stream to minimise pollution of water bodies by excavated material
- On completion of exploration, all trenches were backfilled and where necessary, revegetated

5.3.3.3 *Site Preparation / Mineral Extraction*

Measures taken by RAL to reduce adverse impacts of this phase of its surface gold mining operations in the Manso-Nkran area included:

- Stockpiling of topsoil in all cleared areas to be used for rehabilitation works

- Use of a network of diversion drains and sumps connected to the mine tailings dam to collect all runoff from the mine site, reducing erosion and sediment loading (in rivers / streams) usually associated with cleared areas
- Regular use of water sprays on access roads and mine site to reduce dust emissions, and fitting of mine vehicles with standard exhaust mufflers to reduce noise to acceptable levels
- Implementation of a policy of ensuring that standing water does not remain for more than 7 days, to reduce the incidence of stagnant water creation and associated mosquito breeding / malaria in the mining area
- Use of dust-collection equipment on drill rigs
- Scheduling blasting as much as possible to coincide with favourable weather conditions, in addition to watering of the blast area prior to blasting, to minimise dust pollution
- Reduction of maximum instantaneous charge through delays between blasts and adequate stemming of blast holes (following Environment Australia blasting guidelines as much as possible) with resultant minimal ground vibrations

5.3.3.4 *Beneficiation, Gold Recovery / Bullion Production*

The following measures had been put in place to minimise the adverse impacts associated with this phase of RAL's gold mining activities:

i. *Waste / Runoff Water Management*

Steps taken by RAL to minimise waste / runoff water at its Manso-Nkran mine had included the following:

- A network of drains connected to the mine tailings dam had been strategically located to collect all mine site runoff for conveyance to the tailings dam, with most of the water in the dam being eventually recycled for reuse in the ore processing plant
- As a further step in the water management process, the tailings dam had incorporated in it, a fixed decant system for diverting excess water from the dam into a wetland system created downstream of the main (tailings) dam embankment
- The mine pit had been equipped with a pumping system capable of removing all water in the pit within 24 hours of flooding and discharging it into the tailings dam
- Waste / runoff water in the tailings dam was being effectively managed through a recycling / reuse technique involving the pumping of decant water in the dam via a pontoon-mounted pump system and a return water pipeline for reuse in the ore processing plant

ii. *Management of Waste Dump*

The mine waste dump located to the west of the open-cast pit had been developed using end dumping techniques, with the starter wall developed closer to the mine pit and progressing in development from the north-east to the south-west. Having found through initial estimates that the cost of backfilling the pit with waste material would be prohibitive, a decision was made by RAL to regrade and reshape the waste dump in sections and have them prepared for progressive rehabilitation / revegetation. As one area of the dump (closer to the pit) is prepared and the waste dump points progress to the south-west, sequential rehabilitation / revegetation is carried out on the prepared site. As at the time of the survey, a large portion of the waste dump had already been regraded and reshaped. The surface of the dump had also been topsoiled and planted to several species of local plants. It was disclosed that RAL would continue with the sequential rehabilitation / revegetation programme on the waste dump and several other areas until the cessation of their mining operations in the Manso-Nkran area.

iii. *Tailings Containment / Management*

Mine tailings were being effectively contained / managed by RAL as follows:

- The mine tailings dam had been designed to be capable of storing a 1 in 100 year (72 hour duration) rainfall event without flooding its banks to pollute surrounding land and rivers / streams
- Tailings were being deposited subaerially onto an exposed beach by spigotting from a pipeline. At the initial stages of the project, spigotting had been conducted from a pipeline laid on the top of the tailings dam embankment and ultimately, from the perimeter of the tailings storage area, to attain an even deposition of tailings solids within the storage area. However, when the depth of the deposition reached 300 mm, the spigotting position was changed on a rotational basis to promote maximum drying of the tailings
- To prevent spillage, conveyance of waste from the processing plant into the tailings dam was being done using high density polyetholine pipelines with the joints welded together

- Two saddle dams had been constructed at the upper end of the valley in which the tailings dam is located, to control the flow of tailings back to the main impoundment area, and thus increasing the storage capacity / stability of the dam. Dam stability was being further enhanced by the removal / recycling of decant water in the dam for reuse in the ore processing plant
- A weighted toe with an underdrainage system had been placed at the base of the main embankment of the tailings dam to increase its stability without incurring excessive costs usually associated with the use of a full downstream construction technique
- Lateral and vertical seepage of tailings had been greatly minimised by the provision of a seepage cutoff beneath the main embankment of the tailings dam, and, the use of clay in constructing the basement of the dam. This had greatly helped in minimising pollution of groundwater by contaminants in the tailings. The underdrainage system at the base of the starter embankment had also been equipped with a pumping device to return contaminated water back into the dam
- After an initial evaluation which pointed to the possibility of excess water accumulating in the tailings dam in the future, a spillway was cut through a low valley adjacent to the dam wall, to take any excess water from the dam, to safeguard its stability. As an additional precaution, the phreatic water level in the dam was being monitored (measured) once every year to help assess the effectiveness of the processes / techniques for minimising the amount of water in the dam
- Tailings slurry (47% solids) was being discharged into the tailings dam in thin layers (< 300 mm) to maximise drying, and each layer left to dry out

completely. This is aimed at (i), increasing the density and strength of the deposited material and hence maximise the storage capacity of the dam, and (ii), increasing natural degradation of residual cyanide concentrations in the tailings by desiccation

- To ensure the effectiveness of the tailings management process, once a year, and, preceding the raising of the dam embankment, an inspection of the embankments and review of operating procedures, safety and environmental aspects of the tailings management process had been carried out by an experienced engineer

v. *Minimisation of Environmental Pollution & Sediment Loading in Rivers/ Streams*

Environmental pollution and sediment loading in rivers / streams were being mitigated by RAL as follows:

Use was being made of a wetland filter constructed downstream of the tailings dam. The wetland filter comprises 1.2 km of natural swampland bounded downstream by a low permeable barrier just behind which is a constructed drain leading to the Ayensu Creek further downstream. The 200 metre-long, 2 metre- wide low permeable barrier (separating the wetland and the drain) had been constructed from locally sourced gravel, and covered with a drainage blanket of rip rap (stones and builders), particularly, in the downstream side. The barrier is capable of withstanding periods of high flow and washout during floods. The 1.2-km stretch of natural swampland (wetland filter) operates passively via the swamp's naturally occuring processes of contaminant attenuation.

Excess water discharged into the wetland filter eventually enters the Ayensu Creek via the constructed drain behind the low permeable barrier, and flows down the creek for 1.5 km before entering the Ofin River. The barrier had been fulfilling a vital role in contaminant attenuation and reduction of sediments entering the Ofin River by:

- Increasing the residence time of water discharged to the wetland filter, causing substantial amounts of sediments and debris to settle, and
- Contributing to the filtering of suspended solids directly (by trapping sediments against and within the barrier) and indirectly (by lowering stream velocity and promoting load settling)

Previous test works conducted by RAL had demonstrated the ability of the swamp sediment to adsorb Arsenic, Copper, Zinc and Cyanide at such levels that monitoring of water samples at the point where the Ayensu Creek enters the Ofin River indicated the above pollutants were at non-detection concentrations.

v. *Cyanide Management*

RAL had employed the following measures to reduce cyanide pollution at the Manso-Nkran mine:

- The extensive drainage network upstream of the tailings dam had allowed large quantities of cyanide-free water from the catchment upstream of the tailings storage area to be channelled into the tailings dam. This relatively 'clean' runoff water had been found to significantly dilute cyanide and other contaminants in the decant pond area of the dam

- A number of tests carried on the tailings slurry in the past had indicated that tailings liquor discharged to the tailings dam had a high proportion of free cyanide to total cyanide. This suggested that most of the residual cyanide was present as Hydrogen Cyanide (HCN) and therefore subject to rapid loss through volatilisation. Based on this fact, RAL had taken steps to enhance the processes that lead to increase in the natural degradation of residual cyanide in the tailings by desiccation, including discharging the tailings slurry in thin layers and allowing each layer to dry out completely
- A cyanide detoxification plant – that uses the INCO-SO_2 process – had been installed in the tailings dam, under RAL's Chemical Detoxification Plan. As at the time of the survey the plant had never been used, due to the very low levels of residual cyanide at all sampling points previously monitored – far below the Ghana EPA and World Bank Guidelines. This, notwithstanding, RAL indicated that should the need arise in the future, chemical detoxification of residual cyanide would be undertaken before excess water in the tailings dam would be discharged into the wetland filter system

vi. *Dust Control*

Dust control measures pursued by RAL during this phase of their mining operations had included the following:

- Watering of roads using mobile bowsers especially, during the principal dry season

- Limiting of speeds of mine vehicles to limits that ensure minimal generation of dust
- Extraction of dust from the processing plant's comminution circuit using High Energy Venturi Scrubbers and a Baghouse (synthetic fabric filter system)

vii. *Revegetation, Erosion Control & Minimisation of Sedimentation*

To minimise environmental degradation in the mining area and environs, RAL had taken the following measures among others:

- Using the sequential rehabilitation technique, areas degraded at the initial stages of mining activities and old waste dumps had been stabilised and revegetated – as at the time of the survey, 8000 seedlings of various local tree species had been planted in such areas
- Vertiva grass, Giant Star grass and *Gliricidia sepium* had been planted on slopes around the embankment of the tailings dam and along a slope to the south of the mine pit, to check erosion and reduce sedimentation in rivers / streams in the mining area
- Revegetation of degraded areas was still being carried out at the time of the survey, using seedlings from a nursery RAL had established containing more than a million container-grown seedlings of several local tree species and fruit trees

viii. *Mitigation of Socio-economic Impacts*

The following measures had been taken by RAL to reduce the socio-economic impacts of this phase of their mining operations:

- Provision of alternative sources of water supply (boreholes) to communities whose traditional sources of water had been polluted or rendered unsuitable for consumption / household use through mining activities – as at the end of 1999, 9 communities had been provided with pump-fitted boreholes in addition to public places of convenience at the cost of ¢332,000,000
- Groundwater monitoring was being conducted at strategic points to detect environmental change to ensure groundwater supplies of the local communities were not polluted by leachates from the tailings dam. For instance, a seepage monitoring bore had been installed between the tailings dam and the Koninase bore hole water source
- Mining-related local health and safety problems had been minimised by: (i) minimising dust emissions through regular spraying of haul and service roads to suppress dust, (ii), installation of depositional dust gauges at vantage points in the communities to monitor ambient dust, and (iii), provision of an effective drainage system that minimises the creation of standing water for mosquito breeding
- Regular meetings had been held (and according to RAL, would continue to be held) between RAL's Safety and Environmental Officers on the one hand, and community leaders on the other, to discuss mining related problems ranging from environmental health and safety concerns to environmental issues. Through these regular informal discussions, a number of unforeseen environmental and socio-economic issues of concern had been identified and addressed

ix. *Monitoring*

Since September 1997, RAL has been monitoring pH and concentrations of As and CN (both 'total' and 'free' cyanide), among others, at its Nkran mine. It was reported during the survey that apart from monitoring of dust concentrations in communities close to the mine, no comprehensive air-monitoring programme had been put in place at the Nkran mine. The explanation given was that mining was still being carried out in the oxide ore zone and that processing of the oxide ore did not involve roasting. It was however envisaged that as areas containing transition and sulphide ore deposits get exploited in the future, there may be the need for monitoring of SO_2 and AS_2O_3 as roasting to convert the sulphide to the oxide form of the ore prior to cyanidation may lead to the emission of these harmful gases into the environment. It was also reported that no AMD problems were expected until exploitation of the transition and oxide zone ore had began. Monitoring of particulate dust in selected communities had indicated that the dust levels were well below Ghana EPA's maximum permissible levels at all the monitoring points.

Water quality monitoring points had been located at 22 different sites within the concession (Figure 5.3). On the Ayensu Creek, sediment loading was being monitored along with flow rate both upstream and downstream of the disturbed area of the concession. Results of water quality monitoring at the point where water from the wetland filter (mentioned previously) enters the Ayensu Creek between January 1998 and December 1999 are presented in Appendix 15.

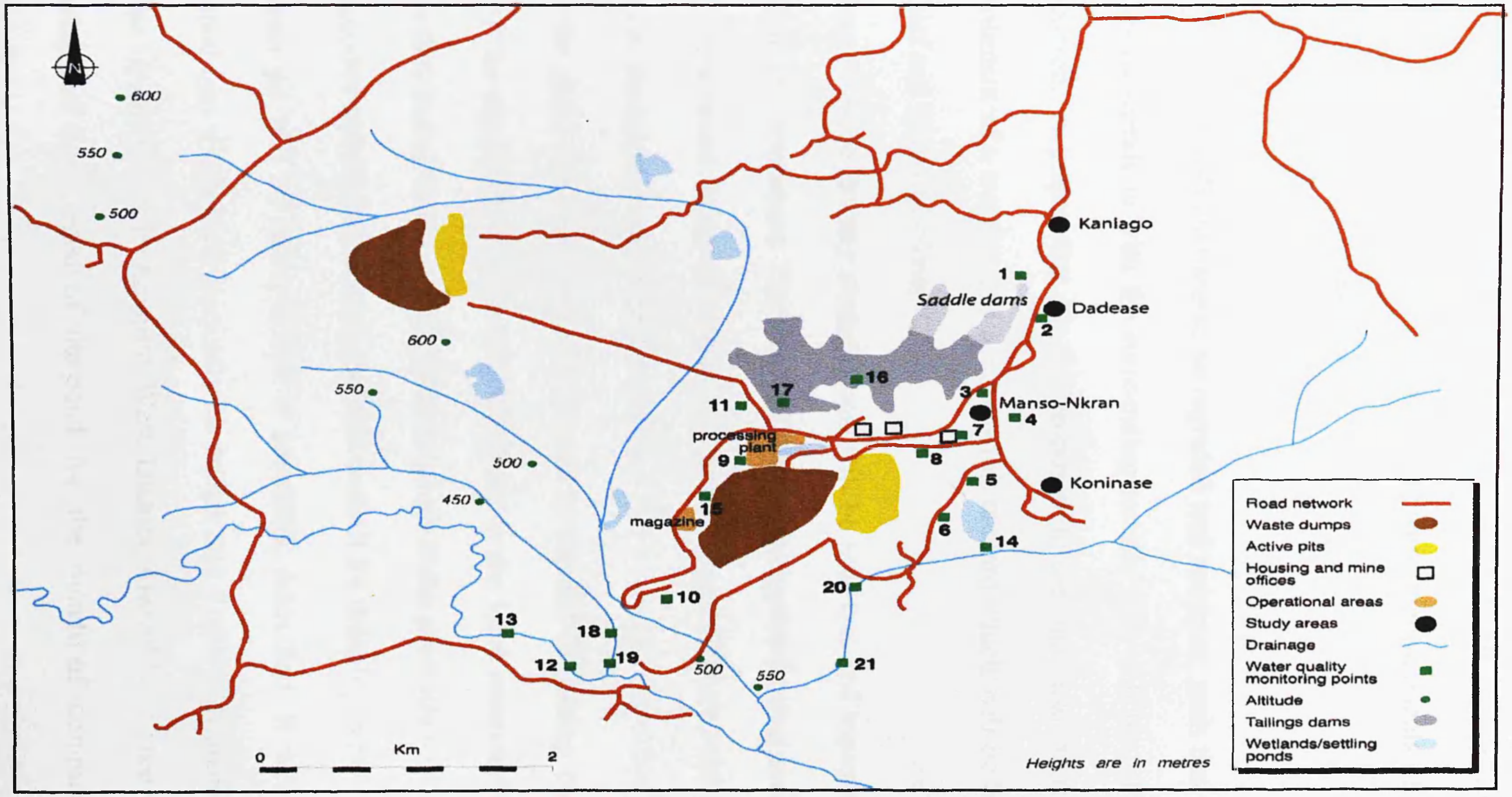

Figure 5.3: Map showing RAL's Water Quality Monitoring Sites (Derived from RAL's Mine Plan and Ghana Topographical Map (Sheet) No. 0603D2)

x. *Post-mining Phase: Mine Closure / Decommissioning*

RAL intends to hand the entire area occupied by its Manso-Nkran mining operations to the surrounding communities in a form suitable for a number of uses. To bring this about, a plan had been drawn up for various components of the mine site to be eventually worked on as follows:

- The waste dump will continue to be regraded and reshaped, such that the final batter angle blends in with the surrounding terrain. This will be followed by revegetation, in preparation for the proposed future land use of the site – establishment of a woodlot and a mixed-fruit orchard which will be handed to the Chief and Elders of Nkran
- The Run-Of-Mine (ROM) stockpile area will be scarified and topsoiled at the end of mining operations. The area will then be revegetated using seedlings of native trees raised in the mine nursery, and made available to the previous owners of the land for agricultural activities
- While the plant site equipment will be sold at the end of mining operations, most of the site buildings will be given gratis to the local communities to be used as they desire. The concrete and foundations at the plant site will be buried and topsoiled and then returned to the local council for redeployment
- The open pit will be reshaped and if necessary, detoxified. It will then be developed into a fish pond stocked with catfish and tilapia. Arrangement will then be made with the Amansie West District Assembly to take over the ownership and management of the pond for the benefit of communities in the mining area

- At decommissioning, RAL intends to pump dry the decant pond on the tailings dam during the long dry season and discharge the water into the natural drainage. The exposed tailings beaches will also be allowed to dry out completely. The entire dam area will then be rehabilitated to a status suitable for the cultivation of low yield pasture

5.4 **Bonte Gold Mines Limited (BGM)**

BGM began alluvial gold mining operations at Tetrem in the Amansie West District of the Ashanti Region of Ghana in 1991, when the Environmental Protection Agency Act 1994 (Act 490) had not come into force. EIA and the preparation of EIS's were therefore not strict requirements for the acquisition of relevant permits and licences prior to the commencement of mining operations. Since 1991, gold has been mined in the valleys of two rivers (Rivers Bonte and Jeni) within BGM's 6,500 ha concession. It must be pointed out that there is a sharp contrast between the operations of BGM and the three other companies selected for this study as regards the mining and processing methods employed. Unlike the other three companies which undertake hard-rock mining operations and employ 'complex' processing techniques to extract and refine gold from the ore, BGM's mining operations involve the use of basic mining equipment for extracting alluvial gold deposits in river valleys. Again, use is made of relatively simple ore processing techniques to refine the gold into a marketable product. BGM's surface mining operations require clearing of vegetation from land overlying alluvial ore. The relatively high water content (10 –15%) means there is not any significant wind erosion, and the relatively flat nature of the floodplain and terrace, combined with rapid re-colonisation by native plants, inhibit any serious soil erosion due to storm water. Drilling, blasting and crushing activities – each, a source of dust and noise in typical hard-rock mining operations – are not undertaken at BGM. The average ore moisture content of > 10% means little or no dust is produced in the mining excavation or the wash plant area. The only significant sources of dust at BGM are from haulage trucks and other mine vehicles travelling on the haulage roads. While problems like sedimentation and turbidity of water bodies are more prevalent at BGM's mine, the fact that no chemicals are used in any of the mineral processing operations means pollution from mineral processing chemicals common to the three other mines is not encountered at BGM's Tetrem mine. In the sections below, BGM's mineral extraction and processing methods are outlined. Positive impacts created by their operations are also highlighted. Measures put in place to minimise adverse mining impacts are also presented.

5.4.1 *Mining and Ore Processing*

BGM's alluvial mining operations begin with the clearance of vegetation in the area to be mined by bulldozers, which are also used to strip topsoil and waste to expose the ore. Trees that are uprooted in the process are cut into pieces and sent to the company's kitchen to be used as firewood. Members of nearby communities are also allowed to collect wood from the cleared areas for use as fuelwood. The exposed ore is excavated with hydraulic excavators and hauled in dump trucks to BGM's wash plant for processing. After removing the ore from the mining area, the waste and topsoil are used to backfill the excavation. Solid waste material from the wash plant, being unreactive, is hauled back to the mining areas to be used in completing the backfilling process.

Since the gold grains are relatively coarse and the ore is naturally liberated from the host material, gold recovery operations involve physical processes only (i.e., no chemicals are used). Ore beneficiation in the wash plant is by gravity concentration (see Figure 5.4). The gold-laden ore is fed into the wash plant with a high-pressure water monitor. A primary scrubber in the circuit removes the few boulders and cobbles present in the ore at this stage. These tailings are stockpiled separately and used for backfilling mined-out areas, or, occasionally, for construction activities related to BGM's operations, such as road or dyke construction. A ball mill is used to break the clay matrix associated with the ore in order to release the occluded gold it may contain. The resulting slurry is routed through a large sluice box for recovery of the gold. The principle of the operation of the sluice box is the difference in the density of gold particles and gangue particles and the resulting difference in their settling times in water. BGM's wash plant recovers approximately 93% of the gold contained in the alluvial ores on the Tetrem concession. The gold concentrate obtained from the sluice box is further concentrated through hand panning and then fluxed, smelted and cast into bullions. Wash plant effluent is discharged into a sand wheel in order to dewater the solids. The resulting solids (sands and silts) are stockpiled and used for backfilling mined-out areas. The effluent from the sand wheel contains about 5% suspended solids and is discharged into settling ponds. The clear water in the ponds is recycled by pumping it back into the wash plant for reuse.

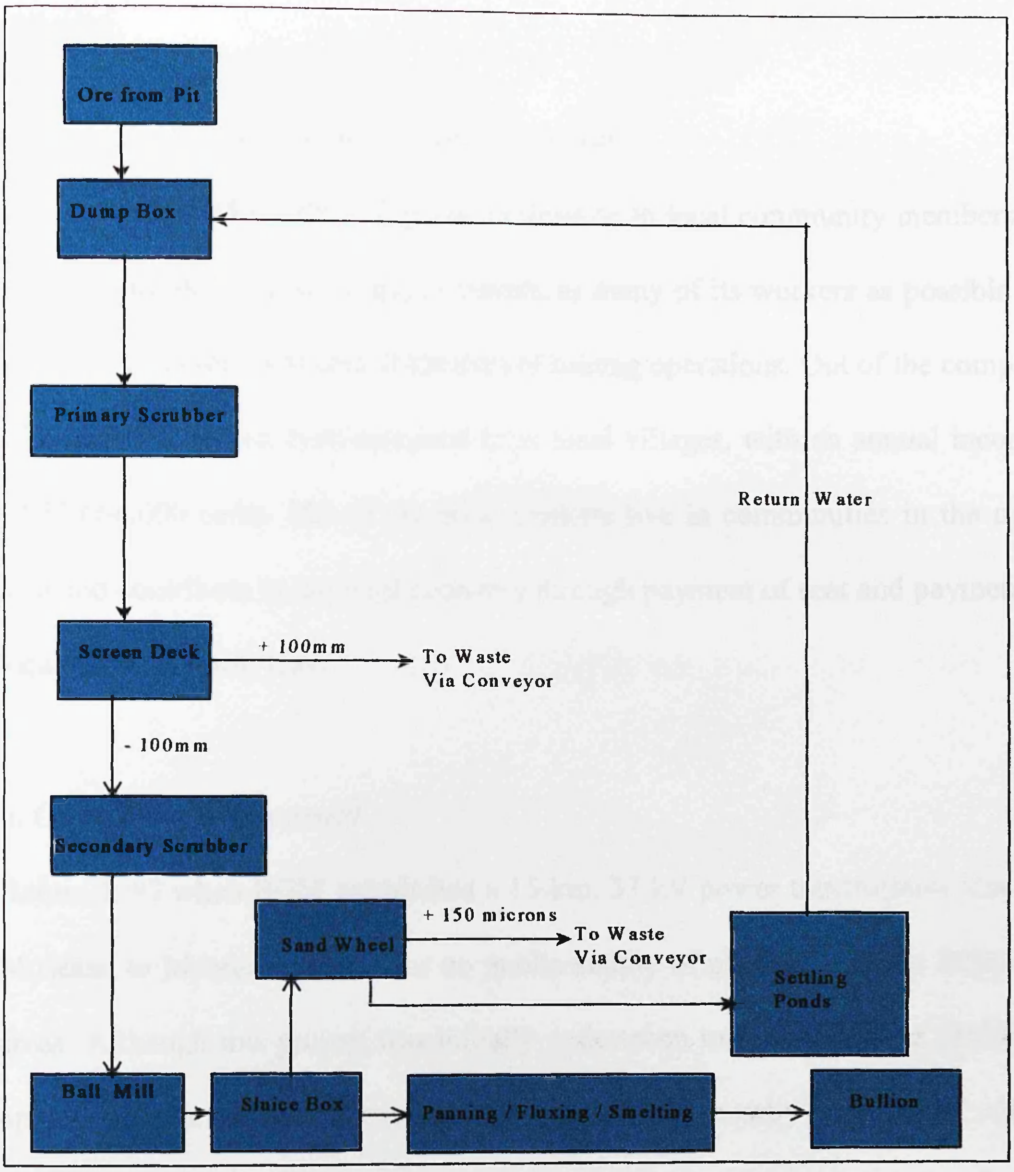

Figure 5.4: A Simplified Flowsheet for Ore Processing at BGM's Wash Plant

5.4.2 *Positive Mining Impacts*

The positive impacts of BGM's activities in the Tetrem area were found to be in the areas of employment and community development, as outlined below:

i. *Employment / Improvement in Local Economy*

In line with BGM's policy of giving preference to local community members with the requisite skills in the hiring of labour, as many of its workers as possible were recruited from the local area at the start of mining operations. Out of the company's 320 workers, 85 had been recruited from local villages, with an annual income of 2,953,664,000 cedis. 200 of the mine workers live in communities in the mining area and contribute to the local economy through payment of rent and payments for local goods and services.

ii. *Community Development*

Before 1997 when BGM established a 15-km, 33 kV power transmission line from Moseaso to Mpatuom, there was no public supply of electricity in the BGM lease areas. Although this project was initially undertaken to provide power for BGM's operations, the company extended the facility to nearby towns and villages (including Aboabo-Tetekaso, Tetrem, Essuowin, Esaase, Ahwerewa, Manhyia, Bonteso and Mpatuom). It was reported (by BGM) that the company had supported a number of community development projects in the areas of water supply, sanitation and health. According to BGM, over the years, a total of 35 million cedis had been contributed to the local communities for improvement in water and sanitation systems, health-related projects and education facilities. BGM had also rehabilitated the main gravel road from Nkawie / Toase to Bonteso / Jeninso, a road which provides an important social and economic link between the villages in BGM's lease areas and the rest of Ghana.

5.4.3 ***Mitigation of Adverse Mining Impacts***

Measures employed to minimise the negative impacts of BGM's mining operations are as described in the sub-sections below.

5.4.3.1 Pre-Mining Stage

Impact-mitigation measures taken by BGM at this stage of its Tetrem mining project are as outlined below:

i. *Baseline Study / EIA*

At the time BGM applied for a mining lease in the Tetrem area (1989), it was not a mandatory (statutory) EPA requirement for mining companies to undertake EIA studies of their operations before being granted the necessary permits / licenses to commence mining operations. However, BGM was obliged to submit to the Minerals Commission and the EPA, an Environmental Action Plan (EAP) covering the status (including environmental conditions) of their concession, the mineral development plan, potential impacts of proposed operations, and an impact-mitigation plan. It was also a legal requirement for them to submit an environmental monitoring programme that would be pursued during the operational phase of the project to the two bodies. This called for a baseline study in and around BGM's concession. The study focused on important components of the environment such as sacred groves, farms, farmlands and water bodies likely to be impacted upon during the constructional and operational phases of the project.

Although details of the specific methods used by BGM to acquire their baseline data were not given, it was reported that generally, standard methods were employed in the acquisition of the following baseline data, which were taken cognisance of in the preparation of the EAP:

- Water resources and quality
- Soil resources and quality
- Flora (vegetation) and land use
- Fauna (game and wildlife)
- Historical / Archaeological resources
- Socio-economic baseline

Table 5.4 shows the physical, chemical and microbiological characteristics of water bodies that were studied in the concession area.

Table 5.4: Characteristics of Water Bodies investigated during BGM's Tetrem Mine Baseline Study

Physical Characteristics	**Chemical Characteristics**	**Microbial Characteristics**
	Concentrations of:	- Faecal Coliform
- pH	- Iron	- Total Coliform
- Conductivity	- Arsenic	
- Total Suspended Solids	- Copper	
- Total Dissolved Solids	- Lead	
- Total Hardness	- Zinc	
- Dissolved Oxygen	- Calcium	

ii. *Consultations / Community Concerns*

BGM held consultations with the local community chiefs and elders, and other stakeholders (including the EPA, the Mines Department and the Minerals Commission) to ascertain the concerns of the local community among other things.

Steps that were taken to address the concerns raised during the consultation process included payment of compensation to displaced farmers, employment of as many of the company's non-skilled labour as possible from the local community, and provision of alternative potable water for the local community. Other measures – including fencing and provision of warning systems – aimed at the protection of public health and safety were also embarked upon.

iii. *Planning*

The following impact-mitigation measures were taken during the planning stage of BGM's mining operations at Tetrem:

- Location of residential quarters, new roads and mine site facilities away from densely forested areas as much as possible, to minimise damage to forests in the concession area
- Location of the mine domestic waste disposal site in an impermeable geological stratum to prevent contamination of ground water by leachate from the site

- As the baseline survey showed that the economy of communities in the mining area depended primarily on cash crop production and subsistence agriculture, mining operations were planned to ensure that agriculture remained the main future land use in and around the concession. To achieve this, a plan was evolved whereby mined out areas were to be continuously and progressively reclaimed / revegetated for agricultural activities in the future
- Having identified during the baseline study that a sacred grove ('Amponsah Sacred Grove') – an ecological reserve of special significance to the local community – existed near Tetrem, mining activities were planned in such a way as to maintain the integrity of the sacred grove

5.4.3.2 *Exploration*

The main steps taken by BGM to reduce adverse impacts of the exploration phase of the Tetrem mining project were as follows:

- The use of a small, hand-powered core-drilling device (a Pionjar Drill) to confirm the presence of gold-bearing gravels, ensuring minimal disturbance to soil and vegetation
- During core drilling, use was made of small diameter holes (< 5 cm) drilled to a maximum depth of approximately 10 m without drilling fluids, oils or other agents – as the drilling units were quite small, only small tracks had to be cleared for access to drill sites
- Rapid backfilling and where necessary, revegetation of holes left after exploration

- Rapid revegetation of exploration tracks after completion of exploration works

5.4.3.3 *Site Preparation / Mineral Extraction*

Steps taken by BGM to reduce the impacts of site preparation and mineral extraction at the Tetrem mine had included the following measures:

- Most construction activities were undertaken in the dry season to minimise erosion and sediment loading in rivers and streams
- Control of dust emissions by limiting mine vehicle speeds to 50 km / h and watering haulage roads regularly with water bowsers
- With the alluvial ores in BGM's concession located in the floodplain and terrace of river valleys, efforts had been made to restrict mining activities to the lower areas of the valleys, consequently causing little significant change in the visual quality of the lease areas
- Maintenance of slope angles at between 65 $^{\circ}$ and 75° in 3 – 7 m deep mining faces during stripping and ore excavation to ensure slope stability in mined-out areas

5.4.3.4 *Beneficiation, Gold Recovery / Bullion Production*

The following measures had been put in place to reduce the adverse impacts associated with this phase of BGM's mining operations in the Tetrem area:

i. *Waste Management / Disposal*

Wastes resulting from mining activities were being managed by:

- Preventing the accumulation of solid waste from ore processing by using tailings (sand and gravel) from the processing plant for backfilling mined-out areas, as part of the reclamation process
- Disposing of waste solvents and oils by storing them in empty drums and selling them to local businesses, thereby minimising the risk of soil and surface water contamination by waste solvents and oils
- Destroying workshop wastes (including rags and filters) by burning them in a pit located in an isolated area

ii. *Reduction of Air and Noise Pollution*

Air and noise pollution had been reduced through: (i) regular watering of roads during the dry season to keep dust levels to a minimum; and (ii) incorporation of a rubber tyre drive mechanism in the processing plant to minimise noise

iii. *Waste / Runoff Water Management*

The following measures had been put in place by BGM to minimise waste / runoff water at the Tetrem mine:

- The mine site had been designed in such a way that runoff water is collected in intercepting ditches which channel the water into settling ponds, enabling reduction of suspended solids and discharge of relatively clean water into the environment

- Sediment loading and water pollution in rivers and streams had been controlled by minimising the amount of water released to the general drainage by recycling as much water as possible for reuse in the processing plant
- Routing of water from the processing plant to settling / tailings ponds to allow suspended solids to settle, and recycling decanted water from the ponds for reuse in the processing plant

iv. *Revegetation, Erosion Control & Minimisation of Sedimentation*

Environmental degradation was being held in check at BGM's mine at Tetrem as follows:

- Some mined-out areas had been reclaimed, following the steps below:

Step 1: Backfilling of mined-out areas with plant tailings (sand and gravel), waste and topsoil soon after ore removal from a particular pit is completed

Step 2: Contouring of backfilled areas to create a natural-appearing landform that would not cause significant ponding of storm waters, and, topography similar to pre-mining conditions re-established wherever possible

Step 3: Recontouring done in any areas where surface drainage is not adequate, and drainage channels re-established where necessary

Step 4: Planting of trees and shrubs obtained from BGM's on-site nursery (containing 42,000 mainly native container-grown seedlings) in backfilled areas to complement the native vegetation which naturally re-establishes itself in most areas. As at the time of the survey, about 75% of backfilling and re-contouring had been completed in mined-out areas, with 11% of mined-out areas revegetated

Step 5: Monitoring of the revegetation process to ensure that eventually, BGM's reclamation efforts result in the re-establishment of productive natural communities. According to BGM, the long term success of the concurrent reclamation programme would continue to be monitored, in order to be able to determine if adjustments to the reclamation plan is required

- In addition to using previous excavations for backfilling, fine soil recovered from settling ponds and tailings from the processing plant were also being used in the backfilling process. The backfilling process is completed by topsoiling and grading the topsoil until a gradient of 0.1% is obtained, before revegetation of the prepared area. Revegetation of the reclaimed land had been done as soon as possible, to minimise soil erosion and gullying in the mined-out areas
- In other devegetated areas of the mine site, fast growing nitrogen-fixing plant species (including *Leucaena leucocephela* and *Cassia siamae*) had been planted, together with Citronella (for soil stabilisation and understorey development)
- In revegetated areas where vegetative growth had been found not to be as fast as on the lower flood plain, seeds of *Centrosema plumeiri* had been broadcast soon after stabilising the land. Centrosema, being a fast-growing creeping plant, had helped to protect the soil surface against erosion by forming a dense net-like structure on the soil when fully grown
- Food crops (including cassava, cocoyam and maize) were being grown on some reclaimed areas on a trial basis, and had exhibited healthy growth
- In some areas, the backfilled floodplain and other reclaimed areas close to the settling ponds had revegetated naturally – colonised by fast-growing aquatic

plants such as *Cortadeila selbana* and *Heliotropium orgeratum*, and, native species such as *Chromolaena odorata* and *Uphorbia hirta*

v. *Mitigation of Socio-economic Impacts*

The following measures had been taken by BGM to reduce the socio-economic impacts of this phase of their mining operations:

- Payment of appropriate compensation to farmers and other local community members whose property had been lost to mining activities in one way or the other
- Installation of alternative sources of potable water supply – boreholes with hand-driven pumps – in villages whose traditional / natural water sources had been polluted by or lost to mining activities
- Fencing and erection of warning signs around mined-out areas awaiting backfilling, and settling / tailings pond areas, to prevent the incidence of local community members falling into these excavations or mistaking water in the ponds for safe drinking water
- Routine maintenance of the main gravel road from Yawso near Nkawie-Toase to Bonteso / Jeninso, at a yearly cost of ¢20,000,000. The road provides an important social and economic link between the villages in BGM's lease areas and the rest of Ghana

vi. *Monitoring*

BGM had been carrying out water quality monitoring at its Tetrem mine on a monthly basis to ascertain whether the quality of water bodies in its lease areas was not being adversely affected by its operations. Potable borehole water was being sampled at Tetrem, Manhyia, the BGM Campsite and Minesite. Water in the River Ofin, into which water from the Jeni River drainage system flows, was also being sampled. The water samples had been analysed for pH, Turbidity, Total Dissolved Solids and Conductivity, and monitoring results reported monthly to the EPA. BGM's water quality monitoring data covering the period 1998 – 1999 are reported in Appendix 16.

To ascertain whether the noise generated by BGM's equipment was affecting nearby communities, noise levels were measured over a 3-month period at Tetrem and other nearby villages in 1998. The results (average values) are presented in Table 5.5. Similar studies were conducted for dust emissions during the same period (Table 5.6).

i. *Post-mining Phase: Mine Closure / Decommissioning*

After assessing and finding that the land use potential of the post-mining mine site is agriculture, a plan had been formulated by BGM to restore the mined land to a state capable of sustaining vegetation. To achieve this, during mining, the topsoil and underlying waste material had been stacked separately on adjacent terrace sites in order to facilitate the replacement of the soil cover on top of the waste when backfilling.

In addition to returning most of the mining area to the local community for agricultural use after decommissioning, most of the mine site buildings that can be of long term use to the community will be given to them free of charge. Repair and

Table 5.5: Night Noise Levels (Average Monthly Noise over a 3-month period in the Dry Season of 1998) at 3 villages Close to BGM's Project Area

Settlement	**Noise Level [dB(A)]**
Aboabo	49.3
Tetrem	52.3
Mpatuom	50.4

**Noise levels were well below the EPAMPL (monthly average) of 70 dB(A) in all three villages where noise levels were monitored over the three-month period*

Table 5.6: Dust Levels (Average Monthly Dust Concentrations over a 3-month period in the Dry Season of 1998) at 3 villages Close to BGM's Project Area

Settlement	**Dust Level (μg / m^3)**
Aboabo	60
Tetrem	70
Mpatuom	72

** Dust levels were below the EPAMPL (monthly average) of 100 μg / m^3 at all three villages where dust levels were monitored over the three-month period*

maintenance of the facilities would then be turned over to the local authorities. With these envisaged land uses in mind, the following activities had been planned to to be pursued at mine closure / decommissioning:

- Settlement ponds will be drained, backfilled with sand and gravel tailings, levelled, covered with topsoil and revegetated with native plants
- The tailings dam area will be recontoured, covered with topsoil and then revegetated
- Concrete foundation at the plant site will be buried with at least 1 m of fill material, recontoured to create a natural-appearing landform, covered with soil and revegetated with shrubs and trees

5.5 **Bogoso Gold Limited (BGL)**

BGL commenced surface gold mining operations near Bogoso in the Wassa West District of the Western Region of Ghana in 1990. Mining activities in BGL's concession actually started on a small scale as far back as 1930, when high-grade oxide deposits were developed as open pits by the then British group, Marlu Gold Mining Limited until 1957 (when Ghana gained independence) when the mine was closed down. During the period, 7.6 million tonnes of ore were milled with 28,740 kg (9,240,000 oz) of fine gold recovered. The concession was acquired by BGL in 1990. Like AGC, BGL has been mining both oxide and sulphide ores in its Bogoso concession. BGL's mining processes and the positive impacts associated with their operations are outlined below, together with measures employed to minimise adverse impacts of their mining operations.

5.5.1 *Mining and Ore Processing*

BGL has been mining gold-bearing ore in the Bogoso area using open-pit mining methods. Prior to winning the ore, overburden is removed. CAT 245B hydraulic excavators with $3.5m^3$ capacity buckets are then used for the excavation of the ore. A single back-up system is used in loading the excavated material into 50T dump trucks, while waste rock is placed in surface dumps. Ore extraction is undertaken concurrently in several locations on the leases within BGL's concession. Once excavated, the ore is hauled to the processing plant. The plant design allows the handling of Run-Of-Mine (ROM) oxide-, sulphide- and transition ore all within the same plant (see Figure 5.5). About 800 mm ROM ore is reduced to -150 mm in a Westwitch Jaw Crusher and later reduced in a Semi-Autogenous Grinding (SAG) mill and ball to about -75 mm. Classification of the SAG-mill tails is done in a cyclone. A set of desliming cyclones in the circuit removes gangue minerals like sericite, chlorite and other clay minerals which interfere with flotation. Oxide ores are channelled into five Carbon-In-Leach (CIL) tanks where gold is solubilised using cyanide, and then adsorbed onto carbon, stripped and electrowon by deposition onto steel cathodes. This is followed by smelting and bullion production. The sulphide ores, on the other hand, are sent to the flotation section containing the five CIL tanks. While the final concentrate (70% solids) is roasted in two fluidised bed fluosolid roasters, the resulting slurry is sent to the mine tailings dam. From the roasters, calcine formed is then sent into two special CIL tanks for adsorption. Transition ores (semi-weathered ores) are treated in blends with sulphide material and the tailings resulting from the treatment process (40 – 60% solids) sent to the mine tailings dam. In either case (treatment of the sulphide ore alone, or a

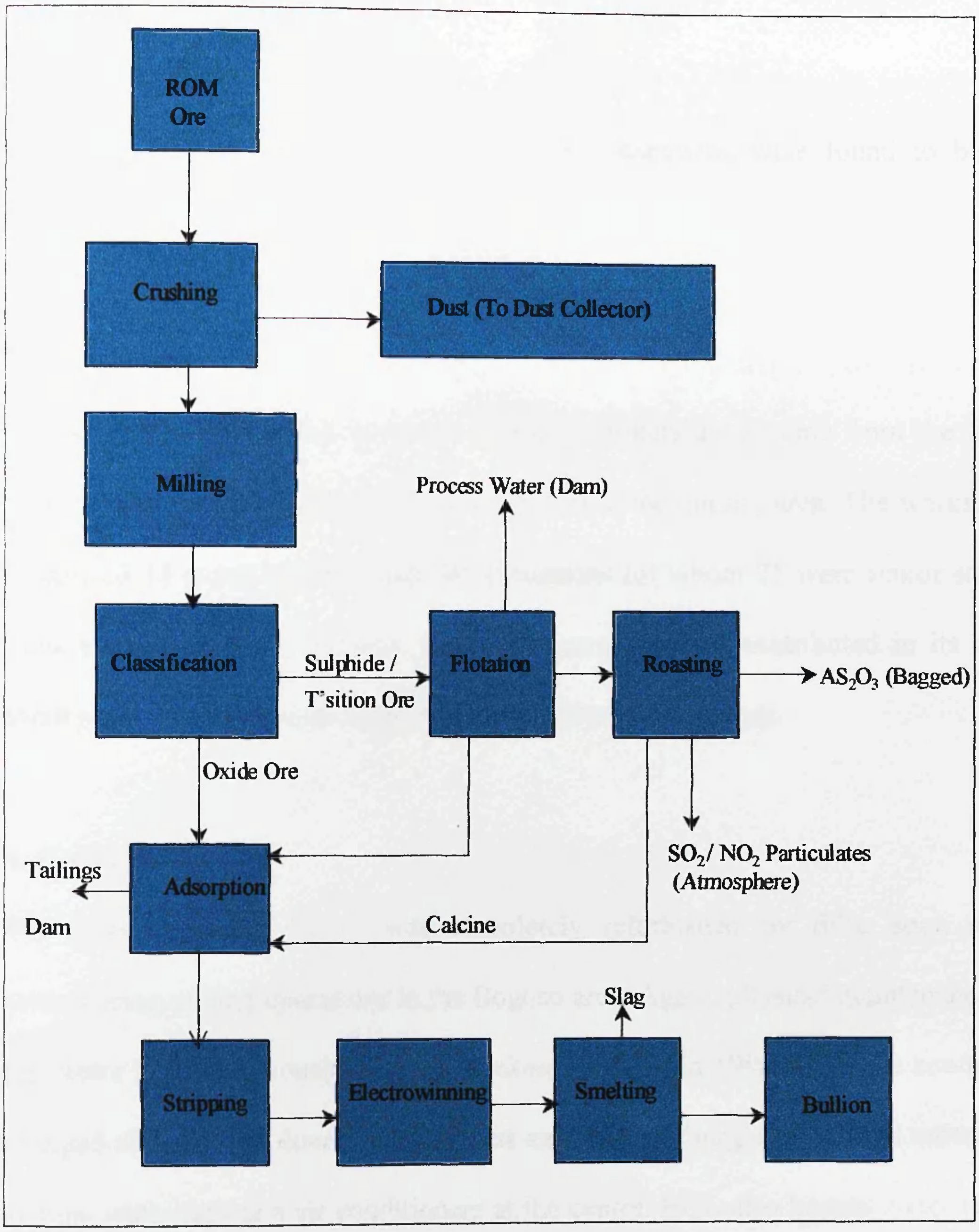

Figure 5.5: A Simplified Flowsheet for BGL's Oxide / Sulphide / Transition Ore Processing

combination of transition / sulphide ores), the gold-impregnated carbon is passed through a stripping column followed by electrowinning and finally, smelting to produce bullion.

5.5.2 *Positive Mining Impacts*

The main positive impacts of BGL's mining operations were found to be as follows:

i. *Employment*

In line with BGL's policy to recruit as many workers as possible from the local area, 10% of its 359 staff had been recruited from the mining area. The workforce comprised 14 expatriate staff and 345 Ghanaians (of whom 71 were senior staff). Thus at both local and national levels, the company had contributed in its own small way, in creating employment opportunities for Ghanaians.

ii. *Health*

The Bogoso Health Centre was completely refurbished by BGL soon after commencing mining operations in the Bogoso area. Again, physical maintenance of the centre had continuously been undertaken by BGL. In 1996 alone, the company changed all locks and doors, repaired fans and changed burglar-proof and mosquito netting, water taps and air conditioners at the centre. BGL also bought water tanks and replaced a submersible pump for the centre in that same year. BGL had also provided the Tarkwa General Hospital with an autoclave. A BGL-constructed clinic at the mine site staffed by a professional doctor and support staff, although used mainly by mine staff, had been made accessible to the general community in emergency situations.

iii. *Education*

The company had provided assistance to educational institutions in its mining area as follows:

- St. Augustine's Secondary School (Bogoso) had been provided with 4 teachers' bungalows, a boys' dormitory, a 1 six-unit VIP toilet and 1 bathhouse at the boys' dormitory
- A Primary School block, a 3-classroom Junior Secondary School (JSS) block, and, a 6-unit VIP toilet had been provided for the people of Domasi
- Financial support had been provided for the construction of the Ebenezer Primary School at Kwameniampa

iv. *Power Supply*

In 1996, BGL constructed a transmission line from the Volta River Authority's (VRA) power supply substation near the mine to Bogoso to supply its own housing complex. The line had been extended to, and power supplied gratis to the Bogoso Health Centre, Bogoso Police Station, the Ghana Water Company Limited's (GWCL) submersible pump, and, street lighting provided for free in the main street of Bogoso.

5.5.3 ***Mitigation of Adverse Mining Impacts***

Steps taken by BGL to mitigate the adverse impacts of their Bogoso surface gold mining operations are as described below:

i. *Baseline Studies / EIA*

BGL commenced mining operations in the Bogoso area at a time when it was not a strict EPA (statutory) requirement for mining companies to undertake baseline studies / EIA as a prerequisite for the acquisition of requisite permits / licences to start active mining. However, it was a requirement for an Environmental Action Plan (EAP) – spelling out steps that would be taken to minimise adverse mining impacts – to be submitted to the Minerals Commission and the Environmental Protection Agency. The EAP had to have a section on 'Description of the Existing Environment' within the mineral concession and its environs. According to BGL, standard methods were employed to obtain baseline information prior to the preparation of the EAP in 1988 (two years before the company commenced active mining operations in the Bogoso area). In the study, many Stone Age sites were found located on the low hills and ridges flanking the central ridge of the concession. Neolithic and pottery sites were also found on hilltops in the concession area. Four shrines linked to the communities of Bogoso, Domasi, Chujah and Kwameniampa were also located in the course of the baseline study. Following the findings, steps were taken to preserve as many of these culturally / historically significant sites as possible.

ii. *Consultations / Community Concerns*

BGM consulted with all appropriate government organisations and community leaders before commencing mining activities in the Bogoso area. Following these consultations, the following measures had been taken among others:

- In consultation with the Land Valuation Board, compensation was paid to farmers and other local community members whose farms or other property were going to be affected by mining
- Fifteen boreholes with pumps and eighteen wells had been provided for communities inside and outside the concession area whose water supply (the quality, quantity or accessibility of rivers / streams) were likely to be negatively impacted upon by mining or mineral processing

iii. *Mitigation of Constructional / Operational Phase Problems*

Specific steps that had been taken by BGL to reduce air emission-, liquid effluent-, solid waste- and community disturbance problems are presented in Table 5.7.

iv. *Monitoring*

BGM had an environmental monitoring programme in place aimed at:

- ensuring that all mitigation and control measures in place were operating efficiently and achieving the desired effect
- ensuring that environmental standards were being met
- detecting changes in the receiving environment which would indicate an environmental problem
- promoting an effective liaison with the local community including addressing complaints and concerns

Table 5.7: Mitigation of Key Constructional / Operational Phase Impacts of BGM's Activities

	Nature of Impact	Mitigation / Control Measures
Air Emissions	Dust and gaseous emissions from blasting	- Use of dust filters on rigs for blast hole drilling - Use of clean stemming in blast holes - Use of suppressed blast design - Watering of the blast pile
	Blast noise and vibration	- Use of minimum blasting distance of 500m from nearest settlement - Evacuation of radius of 500m prior to blasting
	Dust and noise resulting from open pit excavation	- Drop heights of excavated material kept at the lowest practicable level - Water sprinklers used in adverse dry and windy weather conditions - Regular maintenance of, and use of silencers in , heavy equipment
	Dust from tailings dam, haul roads, unvegetated ground, waste rock dumps and stockpiles	- Progressive rehabilitation (where practicable) of waste dumps, tailings dams and mined-out pits - Avoidance (as much as possible) of waste rock dumping and spreading in sensitive areas, especially, during dry and windy weather conditions
	Dust resulting from vehicular movement on mine haul roads	- Use of water bowsers on mine haul roads during dry weather conditions - Maintenance of haul roads including periodic use of rollers to compact road surface - Use of site speed restrictions
	Noise from process plant and vehicular movements	- Regular maintenance of, and use of silencers in , heavy equipment - Use of haul roads mainly / avoidance of use of public roads by mine vehicles as much as possible
	Vehicular emissions	Regular maintenance of mine vehicles

Table 5.7 Ctd.		
Liquid Effluents	Pollution from exploration drilling fluids / spillages	- Drill rigs maintained in good condition to prevent oil leaks and spillages - Drill pads constructed such that storage area for daily fuel, hydraulic oil and drilling fluid supplies drain into a sump - Recycling of drilling fluid and use of biodegradable fluid where possible - Removal and safe disposal of all litter (including steel drums) on moving from one drill pad to another
	Flooded pits with potential for low pH and elevated metal concentrations	- Mined-out pits not intended to be backfilled flooded to prevent AMD generation - For pits requiring dewatering (for operational purposes), water either pumped to the processing plant for use or lime-treated prior to discharge to natural water courses, ensuring discharge water quality is in compliance with Ghana EPA water quality guidelines
	Run-off from site roads, waste dumps, stockpiles, plant yard / processing plant area	- Regular maintenance of haul roads and use of rollers to compact road surface - Progressive rehabilitation / revegetation of waste dumps - Capping of waste dumps containing transition / sulphide material with a layer of oxide waste prior to revegetation - Construction of drains on waste dumps to facilitate rehabilitation and reduce erosion - Reduction of the time for open storage of ore and waste stockpiles - Use of drainage and settling ponds to settle out suspended solids - Maintenance of surface of plant yard by compacting and rolling
	Leakage of process chemicals from plant, and, leakage / spillage of oils / fuels / liquid reagents	- Maintenance of process tanks / equipment and fuel tanks within a sealed, bunded area, and keeping bund clear of debris
	Leakage of tailings from pipeline	Regular visual inspection of pipeline
	Seepage of tailings liquor from tailings dam	- Sumps constructed at toe of dam embankment, into which seepage from the south embankment wall drains and is pumped into the tailings dam - Discharge of seepage from dam embankment into natural water

Table 5.7 Ctd.		
		Courses
Liquid Effluents	Discharge of surplus supernatant water from tailings surface	Controlled discharge to Lake Marwood following chemical analysis to ensure Lake water is not polluted
	Potential failure of tailings dam and associated environmental pollution problems	- Minimum beach length maintained at 50m for supernatant pond control - Minimum freeboard of 1.5m between pond and crest in normal conditions - Monthly visual inspection undertaken by independent engineering consultants
	Sewage storage and disposal	- Regular emptying of tanks by authorised contractors and disposal of sewage into tailings dam
	Accidental spillage of fuel, oil or chemicals during transport to and from mine	- Action taken according to BGL's Medical Evacuation Plan and Emergency Response and Contingency Plan
Solid Wastes	Disposal of waste rock at waste dump sites	- Dump designed to minimise land-take - Progressive rehabilitation of waste dumps wherever practicable
	Disposal of refuse including laboratory waste and used storage containers	Disposed of in an impermeable rocky area on-site
Community	Socio-economic problems due to destruction of farms / farmlands, and influx of population into communities surrounding mine	- Establishment of an Agricultural Assistance Programme (farmers provided with technical advice and assisted with loans / agricultural inputs to embark on scientific methods of farming - Provision of assistance for establishment of additional infrastructure such as school buildings and electricity, and, provision of potable water supplies and recreation facilities - Employment policy to recruit as many staff as possible from the local community - An area of land in the concession near Kwameniampa set aside for small scale ('Galamsey') mining activities by local artisanal miners

The company has been undertaking fortnightly water quality monitoring at strategic sites both within and outside its concession (see Figures 5.6 – 5.8). Parameters monitored at the sites have included pH, Electrical Conductivity, Total Dissolved Solids and the concentrations of As, Cu and Zn. Unfortunately, BGM's environmental / water quality monitoring results were not made available.

v. *Post-mining Phase: Mine Closure / Decommissioning*

After mine closure / decommissioning, BGL intends to use most of the mined-out pits for aquaculture and the waste dump and other degraded areas for silviculture / cultivation of economic plants such as citronella. A plan had therefore been drawn up in line with the proposed future land use of the mine site as follows:

a. *Reclamation of Mine Pits*

Reclamation of deep pits would be carried out by flooding the pits with run-off water diverted from the watershed till the final water level reaches a depth of 3 – 5 m above the level of the transitional ore zone. As the pit fills up, it would be treated with lime to neutralise the acidic water. Any excess water will be discharged directly to the natural drainage channel via a runoff diversion channel. Where transitional ore is not encountered, the area will be smoothened with a bulldozer. Smooth slopes will then be reclaimed by establishing plantations to combat erosion and flat areas revegetated using local plant species.

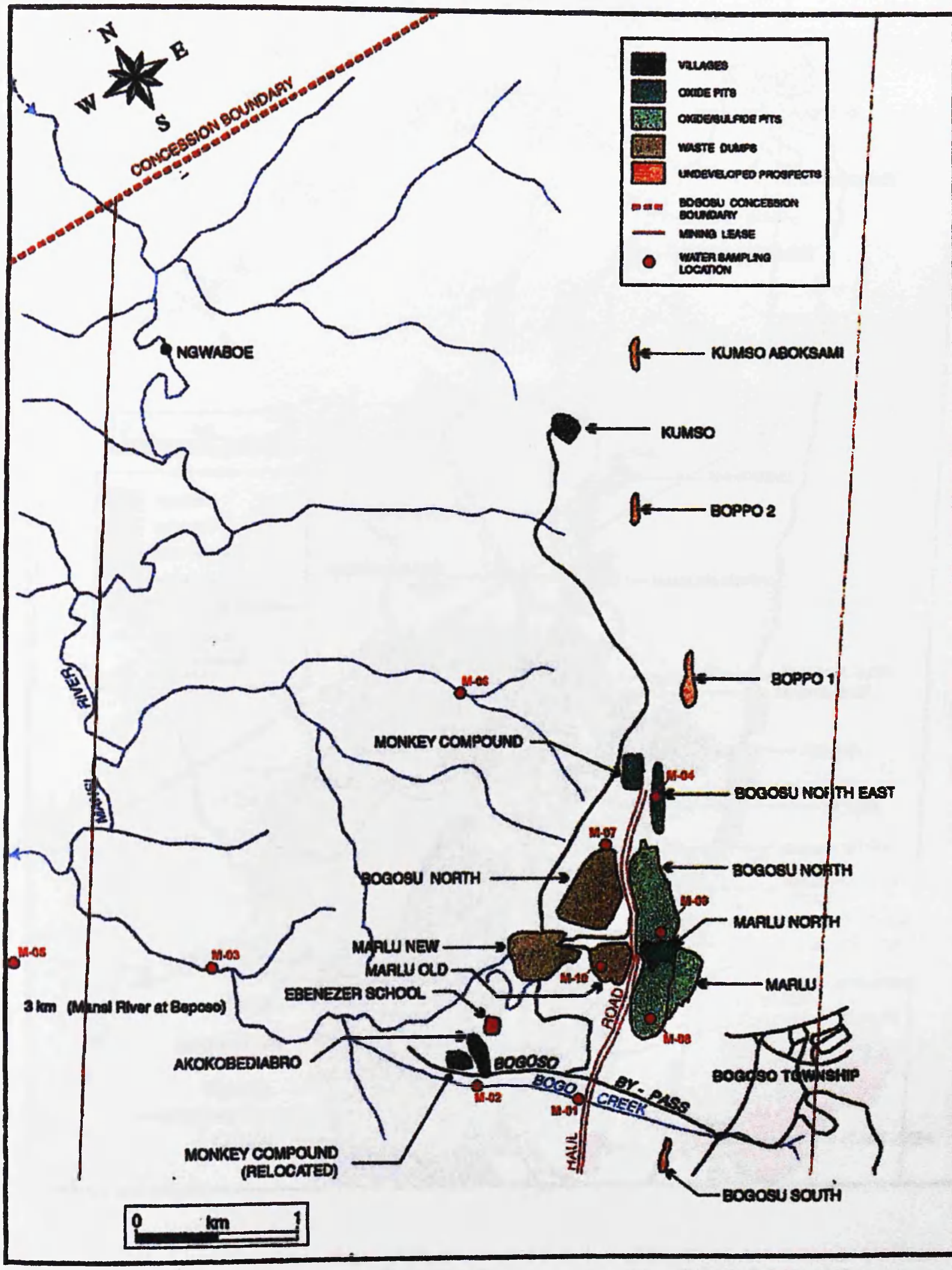

*Figure 5.6: BGL's Mine Plan showing Water Quality Monitoring Sites (labelled '**M**', with corresponding Number of site) in the 'Northern Concession Area'*

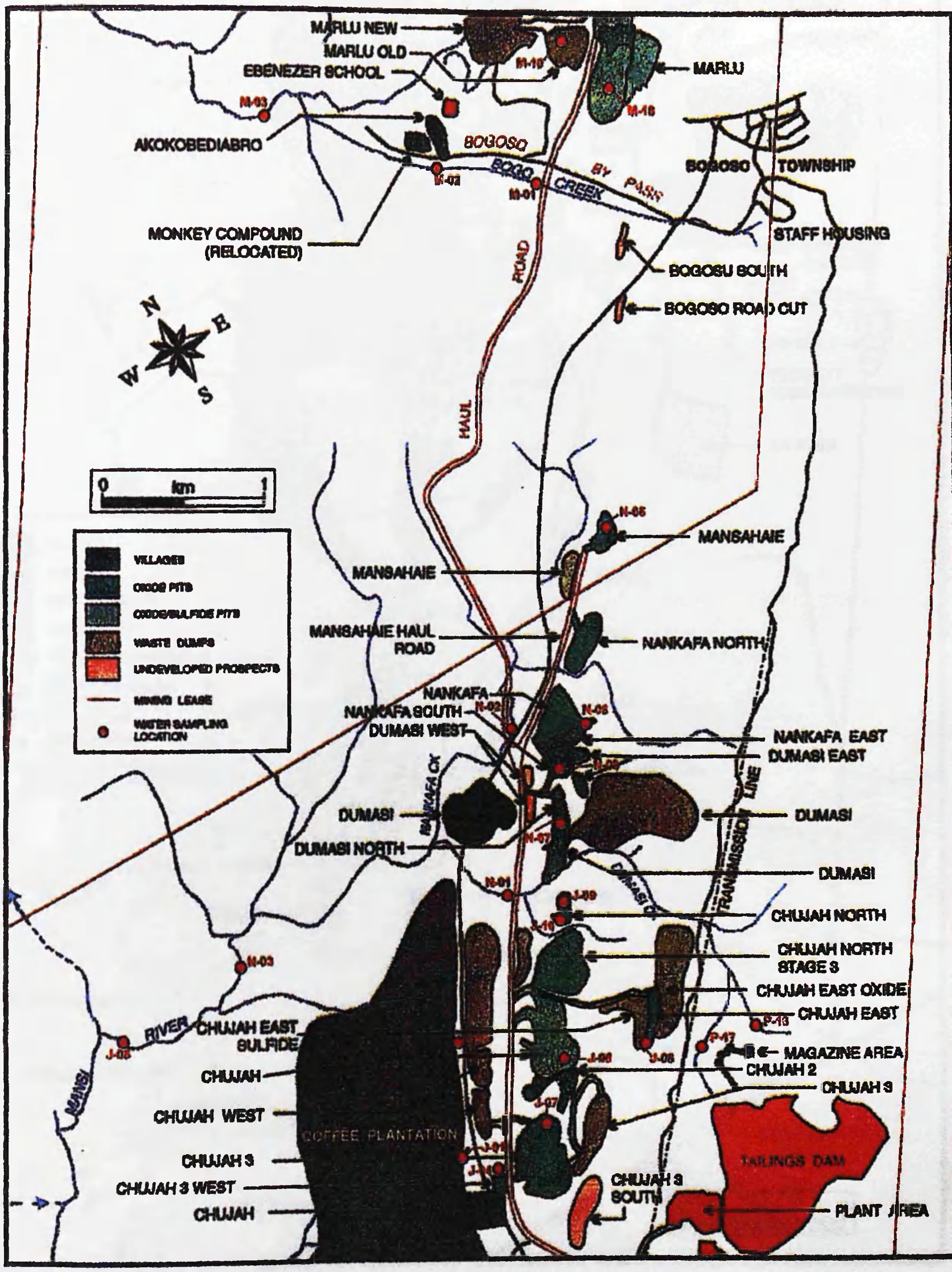

*Figure 5.7: BGL's Mine Plan showing Water Quality Monitoring Sites (labelled '**M**', with corresponding Number of site) in the 'Central Concession Area'*

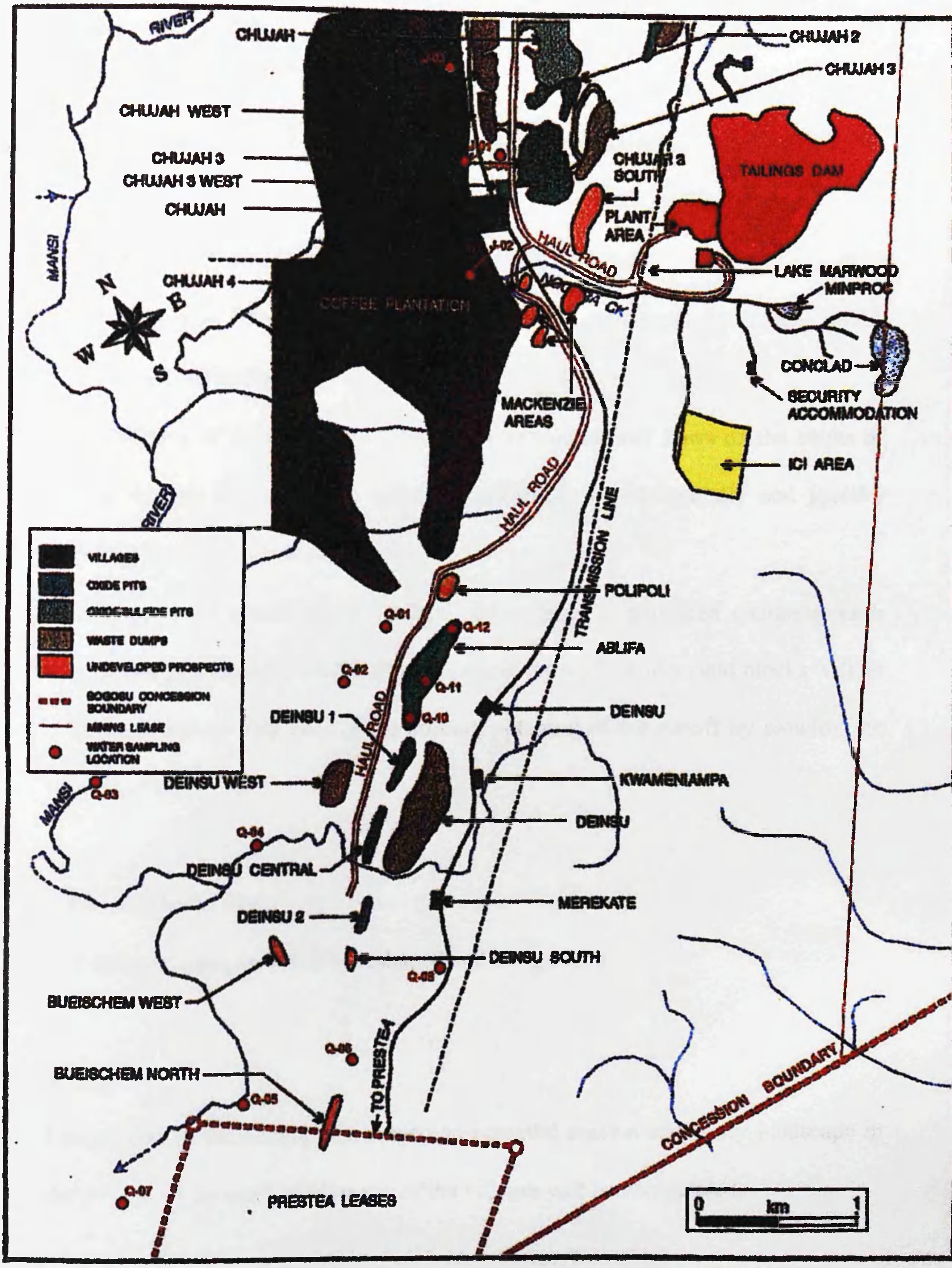

Figure 5.8: BGL's Mine Plan showing Water Quality Monitoring Sites (labelled **'Q'**, *with corresponding Number of site) in the 'Southern Concession Area'*

b. *Waste Dumps*

The following steps will be taken to reclaim mine waste dumps:

- Capping of exposed parts of potentially acid-forming rock
- Reshaping of rounded tops in order to minimise any potentially eroding runoff loads on the banks of the dump
- Reshaping of steep slopes – to minimise eroding runoff flows on the banks of the dumps, wide benches will be constructed sub-horizontally and thereby interrupt and divert the flow
- Diversion of runoff on the surface of the dump – armoured channels, each consisting of a ditch lined with a permeable layer of boulders and blocks will be constructed to help control the eroding potential of the runoff by slowing the rate of water flow

c. *Ore Stockpiles Area*

The ore stockpiles area will be reshaped and revegetated

d. *Slopes*

Every slope in the mining area subject to potential erosion and every landscape in direct view of the main road or any of the villages will be revegetated.

e. *Site Works*

Demolition of the processing plant will start with the pumping to the tailings dam of all remaining process solutions in the plant. Surplus chemical stocks will be returned to their suppliers. Once the plant has been drained, items or equipment of resale value, e.g. pumps, valves and crushers will be removed and sold before the steel framework is dismantled. The scrap will be placed in a pit and covered with excavated soil. The site will then be covered with an 0.5 layer of oxide waste material.

CHAPTER SIX

RESULTS: COMMUNITY SURVEYS

6.1 Introduction

The overall objective of the community surveys (the description of how they were conducted has been presented in Section 3.4 – Chapter 3) was to explore the value of, and develop a procedure by which, community questionnaires can be employed to assess the severity of negative impacts of, and benefits derived from, gold mining in Ghana. Such a tool is required in countries where environmental data is lacking and to prioritise limited resources for mitigation of environmental and social impacts. Specifically, the community surveys were conducted to:

- Assess if questionnaires can be used to assign relative values to impacts of an individual mine on local communities
- Develop a protocol to assess environmental impacts and social significance of mining

Due to the problem of having community members rank mining impacts in order of magnitude using conventional methods as already explained in Chapter 3, a system of ranking and quantification of impacts was developed based on the percentage of respondents (Table 6.1). By calculating the average percentage of respondents complaining about or acknowledging a particular impact, the extent of positive or negative impacts of mining on the various communities could then be estimated and compared. To compare the severity of some of the adverse mining impacts within communities in a particular mining area, or between different mines, an arbitrary scale of 1 – 5, with 1 denoting 'No Impact' and 5 representing 'Severe Impact' was devised (see Table 6.1). The two ranking systems were to measure the severity of environmental and social impacts of, and the significance of beneficial impacts of, mining on communities in the study area. Percentage of respondents complaining about or acknowledging a particular adverse or beneficial impact was used as a measure of the severity of the adverse impact or the extent of the beneficial impact. In the scoring system, a 100% score is equal to a severe impact or great benefit, while 0% equates to no impact or benefit (Table 6.1).

Table 6.1: Scoring System for Adverse and Beneficial Mining Impacts on Communities in the Study Area

Percentage of Respondents	**Severity of Negative Impact**	**Extent of Beneficial Impact**	**Severity of Impact on Arbitrary Scale**
80 – 100%	Severe Impact	Substantial Benefit	5
60 – 80%	High Impact	Major Benefit	4
40 – 60%	Significant Impact	Significant Benefit	3
20 – 40%	Limited Impact	Limited Benefit	2
0 – 20%	No Impact	No Benefit	1

The scoring system was used to assess individual impacts and benefits. For a particular mine or village, a total environmental assessment score was derived by determining the average value across all major attributes. By averaging mine and village scores, a total EIA and social significance assessment score for a particular impact could then be estimated for the mining region.

The main limitations of the above approach are:

- Scoring ignores age, gender, employment sector, and social status
- Surveys may not match with the demographic and social structure of the population

Although the approach used for the community surveys had the limitations listed above, it is worth stating that it can be:

- A useful methodological approach for the assessment of perception-based environmental and social impacts of mining in rural areas in Ghana
- A useful tool for the assessment of the severity of the adverse impacts of, and social significance of environmental impacts and benefits associated with, gold mining in rural Ghana

Presented below are the results of the community surveys in the four mining areas.

6.2 **Mining Impact on the General Community**

Figure 6.1 shows the proportion of various occupation groups among the 320 interviewees from the general community in the study area. As the pie chart shows, while more than a third of the respondents were farmers, very few (1%) of them were fishermen. Mine workers constituted only 4% of the 320 interviewees.

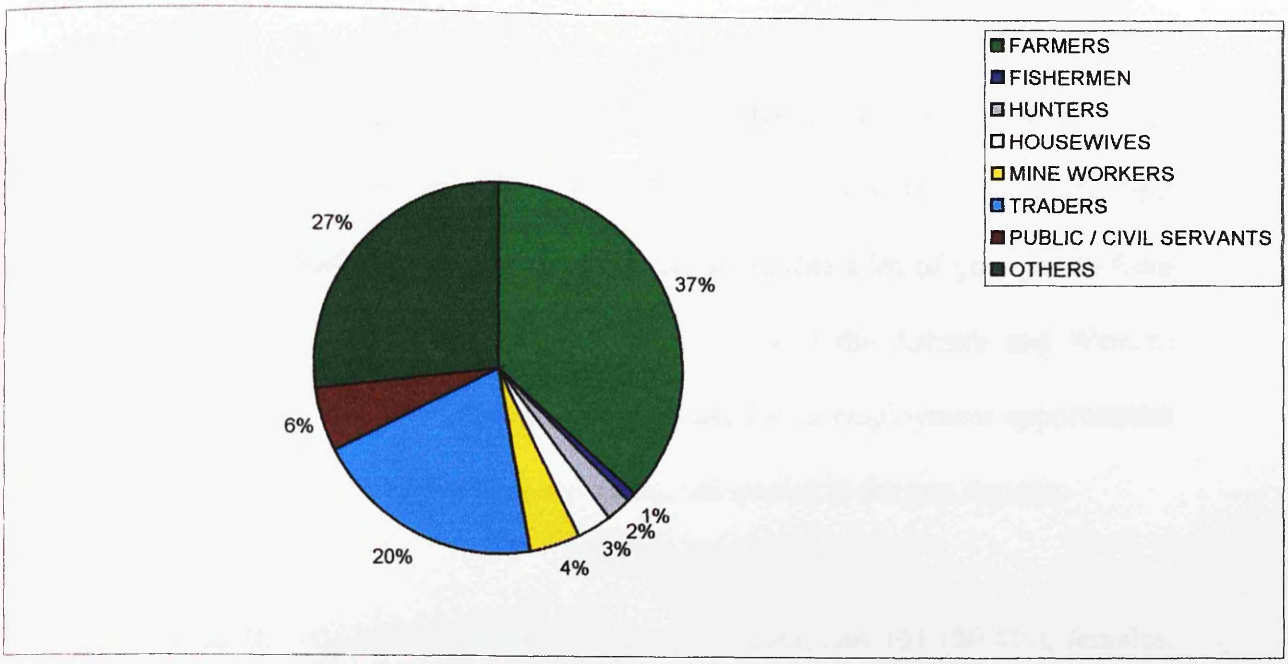

Figure 6.1: Proportion of the 320 Respondents in various Occupation Categories

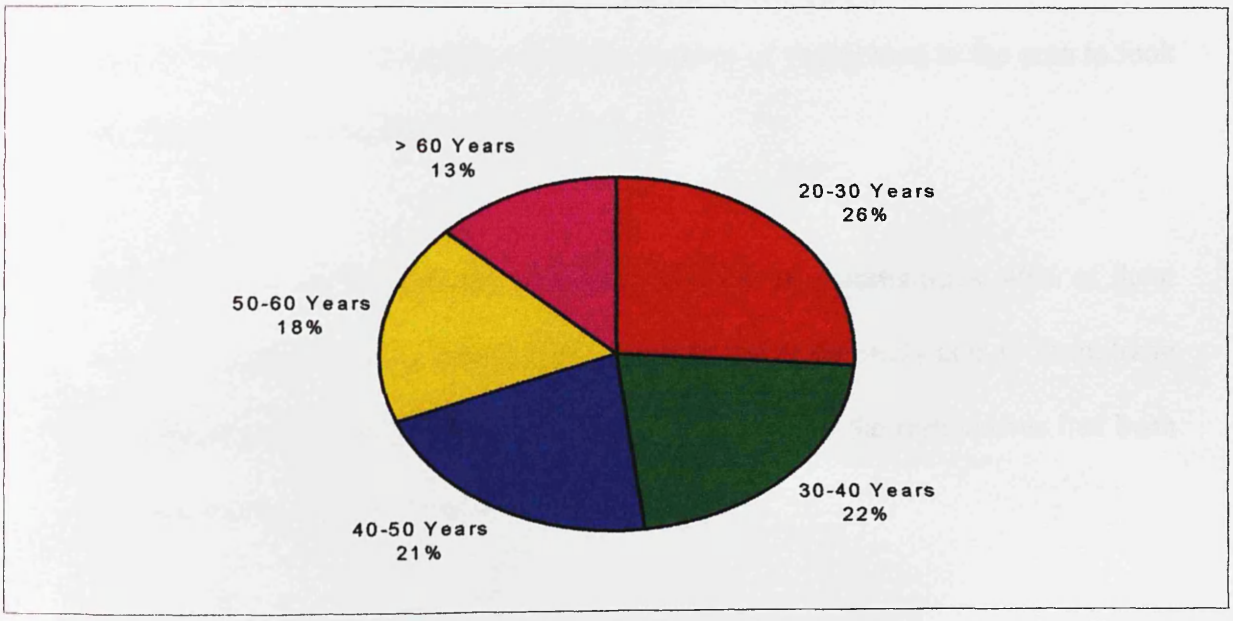

Figure 6.2: Proportion of Respondents (from the General Community) in various Age Classes

As shown in Figure 6.2, most of the respondents were in the 20 to 30-year age group (26% of respondents), with only 13% of them in the 60^+ age group. It must be pointed out, however, that the population figures stated here differ from that encountered in a typical population structure of Ghana. For instance, while young people (people between the ages of 15 and 44) make up 40% of the population, this present study did not include people below the age of 20 (see Section 3.4.1–

Chapter 3). Even with this group excluded from the community survey, it can be seen that 'young people' (people between the ages of 20 and 40) in this study form 48% of the population. This is not surprising, given that a lot of young men from other parts of Ghana have migrated to many parts of the Ashanti and Western Regions of the country (including the study area) due to employment opportunities provided by the numerous mining and timber companies in the two regions.

Out of the 320 interviewees, 159 (49.6%) were males, and 161 (50.4%), females. This male to female ratio of about 1:1.016 differs from the national ratio (1 male: 1.1 female). This may be due to the small sample of the population interviewed or may be explained by migration of a large number of young men to the area to look for menial jobs at the mines in the region.

While 54% of the respondents were natives of the 16 communities, 46% of them were non-natives who (or whose family) had moved to the study area to farm, trade or work at a mine. As shown in Figure 6.3, nearly half of the respondents had been resident in the study area for more than 30 years.

The characteristics of the general community, as obtained in each mining area (80 respondents per mining area) are summarised in Table 6.2. It can be seen from the table that a large proportion (between 31 – 39%) of the population in each mining area consists of people who have spent less than 20 years in the region. This may be put down to the continuous influx of migrants into the study area due to the wide range of opportunities presented by mining operations in the region (including jobs at the mines and enhanced trading opportunities). In the sections below, the responses of the 16 communities regarding the positive and negative impacts of mining on their environment and socio-economic lives are outlined. The types of measures they would like the mining companies operating in the study area to put in place to mitigate the adverse impacts of their operations are also presented.

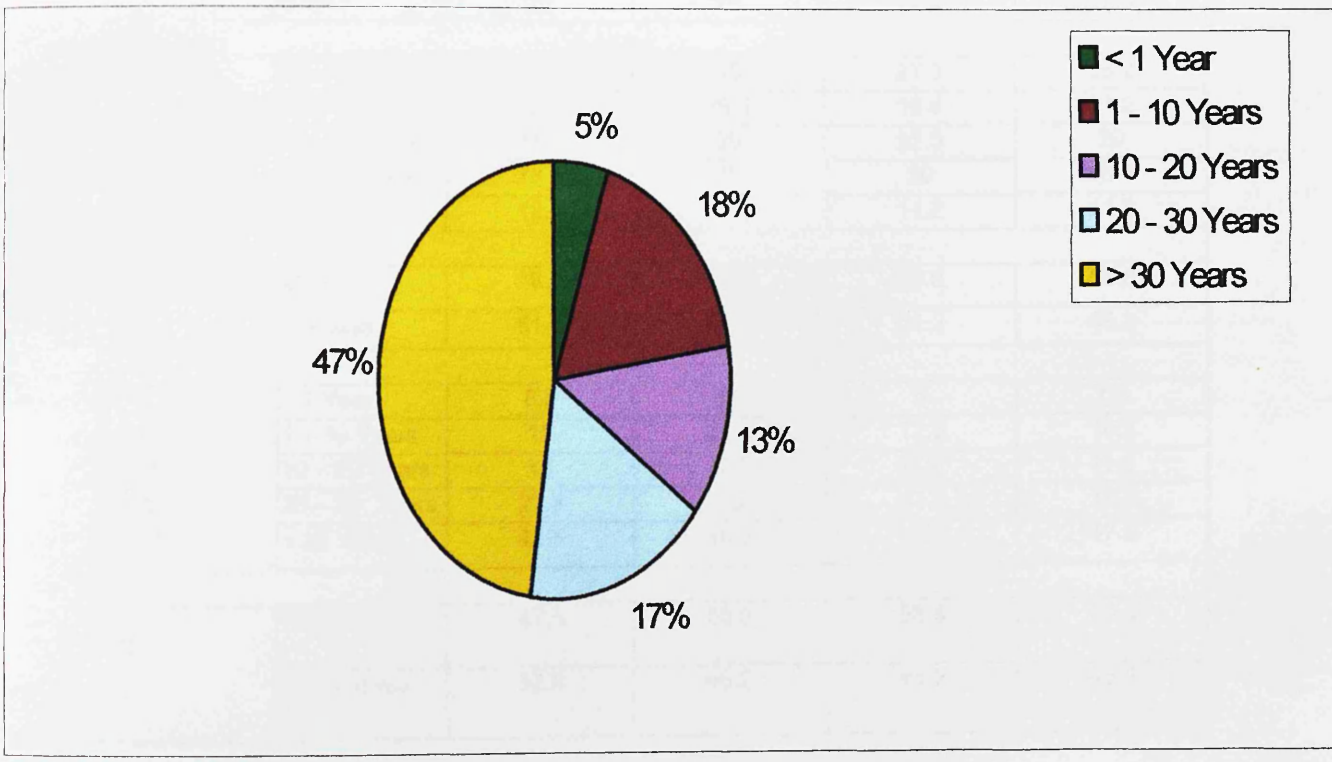

Figure 6.3: Proportion of Respondents and the Number of Years they had spent in the Study Area

6.3 Positive Mining Impacts

Community perceptions of the beneficial impacts of mining operations in the four mining areas (see Figures 3.6 – 3.9) are summarised in Table 6.3. The perceptions are described in detail below.

Table 6.2: Characteristics of the General Community in the four Mining Areas

Characteristics of Communities		AGC Mining Area (% Respondents)	RAL Mining Area (% Respondents)	BGM Mining Area (% Respondents)	BGL Mining Area (% Respondents)
Occupation	Farmers	23.7	42.5	37.5	40
	Fishermen	0	3.7	0	0
	Hunters	2.5	2.5	1.3	2.5
	Housewives	8.8	2.5	1.3	1.3
	Mine Workers	5	3.8	6.2	2.5
	Traders	22.5	18.7	23.7	18.7
	Civil servants	7.5	6.3	3.8	7.5
	Others	30	20	26.2	27.5
Age Class	20 – 30 Years	25	25	27.5	26.2
	30 – 40 Years	22.5	26.2	18.8	21.2
	40 – 50 Years	21.2	20	22.5	20
	50 – 60 Years	18.8	15	20	18.8
	> 60 Years	12.5	13.8	11.2	13.8
Sex	Males	48.8	47.5	48.8	53.8
	Females	51.2	52.5	51.2	46.2
Years in Community	< 1 Year	6.2	1.2	5	7.5
	1 – 10 Years	15	21.2	17.5	16.2
	10 – 20 Years	15	16.3	8.8	11.3
	20 – 30 Years	21.3	15	13.7	17.5
	> 30 Years	42.5	46.3	55	47.5
Origin	Natives	47.5	53.8	58.8	56.2
	Non-natives	52.5	46.2	41.2	43.8

i. *Employment*

As shown in Table 6.3, respondents in the RAL and BGM mining areas described mining-related employment as providing a 'substantial' socio-economic benefit to members of their communities. Respondents in the BGL mining area described employment as a 'major' benefit of BGL's mining operations in the Bogoso area, while it was described as providing a 'significant' benefit by respondents in the AGC mining area. With the exception of the BGM mining area where in each community employment was perceived as a 'substantial' benefit, perception of

Table 6.3: Positive Mining Impacts as Perceived by the General Community in the Study Area

Mining Area	Communities	Distance from Mine (km)	Perception of Positive Mining Impacts (% Respondents)					
			Employment	Provision of Potable Water	Provision of Schools	Provision of Clinics / Health Facilities	Improvement in Roads / Road networks	Enhancement of Trade
AGC Mining Area	Sansu	0.05	50	20	0	0	0	75
	Aduaneyede	9.00	55	55	0	0	0	55
	Ahansonyewodea	12.00	85	90	0	0	0	85
	Ampunyasi	18.00	0	0	0	0	0	30
	% Respondents (Average)		**47.5%**	**41.2%**	**0%**	**0%**	**0%**	**61.2%**
	Estimated Benefit		**Significant Benefit**	**Significant Benefit**	**No Benefit**	**No Benefit**	**No Benefit**	**Major Benefit**
RAL Mining Area	Manso-Nkran	0.85	100	100	95	0	90	95
	Koninase	3.20	95	100	100	0	90	100
	Dadease	4.50	75	60	0	0	90	85
	Kaniago	7.00	75	100	0	0	75	100
	% Respondents (Average)		**86.2%**	**90%**	**48.8%**	**0%**	**86.2%**	**95%**
	Estimated Benefit		**Substantial Benefit**	**Substantial Benefit**	**Significant Benefit**	**No Benefit**	**Substantial Benefit**	**Substantial Benefit**
BGM Mining Area	Tetrem	0.50	100	100	0	0	0	100
	Bonteso	1.60	100	100	0	0	0	100
	Mpatuom	5.00	100	40	0	0	0	95
	Jeninso	7.50	95	0	0	0	0	100
	% Respondents (Average)		**98.8%**	**60%**	**0%**	**0%**	**0%**	**98.8%**
	Estimated Benefit		**Substantial Benefit**	**Significant Benefit**	**No Benefit**	**No Benefit**	**No Benefit**	**Substantial Benefit**
BGL Mining Area	Chujah	0.03	100	90	0	0	40	90
	Odumasi	0.25	100	100	90	0	40	100
	Kumsono	2.50	0	65	0	0	30	85
	Kwameniampa	3.60	100	0	95	0	20	100
	% Respondents (Average)		**75%**	**63.8%**	**46.3%**	**0%**	**32.5%**	**93.8%**
	Estimated Benefit		**Major Benefit**	**Major Benefit**	**Significant Benefit**	**No Benefit**	**Limited Benefit**	**Substantial Benefit**

* 0 ⇒ *None of the interviewees included parameter on top of column on their list of percieved positive mining impacts*

employment as a beneficial mining impact differed from community to community in the various mining areas. In the AGC mining area for instance, half (50%) of respondents at Sansu – where most of AGC's surface mining activities are currently concentrated – saw employment as a positive mining impact of AGC's activities. However, at Ampunyasi, a village 18 km from the current mine site, none (0%) of the respondents thought employment was a positive mining impact of AGC's mining operations on the socio-economic lives of their community members. In fact, all respondents there indicated that not a single member of the community was employed at the mine. In contrast, at Ahansonyewodea which is 12 km away from the current surface mine site, as much as 85% of respondents felt employment opportunities created by AGC had led to improvement in the socio-economic lives of community members. Discussions with the Village Development Committee of Ahansonyewodea revealed that AGC employed lots of the youth in the village several years ago for menial jobs at the then underground mine at Obuasi and most of them were retained when it commenced surface mining activities at Sansu a few years ago. Only 55% of respondents at Aduaneyede (9 km from the current mine site) considered employment as a positive mining impact of AGC's surface mining operations.

Although not confirmed by AGC, it seems that during employment of rural community members in the Obuasi area by the company, preference is given to communities as close to the mine as possible.

In the RAL mining area, all (100%) respondents from Manso-Nkran, 95% of the Koninase respondents and 75% of the Dadease and Kaniago respondents were of the view that RAL had contributed significantly in the creation of jobs for people in their respective communities. Each of the communities had a significant proportion of its members employed by RAL. In three of the communities in the BGL mining area, all (100%) respondents from the general community thought BGL had made a positive contribution to the local economy in the area of job creation. However, in one community (Kumsono), none (0%) of the respondents thought this way. According to the Kumsono respondents, none of their community members had been employed by BGL.

ii. *Provision of Potable Water*

It was only in the RAL mining area that 'provision of potable water' was described as a 'substantial benefit' of mining activities. While respondents in the BGM and BGL mining areas described this positive mining impact as a 'major benefit', it was rated a 'significant benefit' by the respondents in the AGC mining area. From community to community in each mining area, the rating depended on a number of factors, as described below.

In the AGC mining area, it was only at Ahansonyewodea that most (90%) of respondents indicated AGC had provided the community with adequate potable water after destruction of previous potable water sources – rivers and streams. Few respondents in the area (20% at Sansu, 55% at Aduaneyede and none at all [0%] at Ampunyasi) expressed satisfaction about provision of satisfactory alternative potable community water source by AGC. At Sansu, most (80%) community members felt the Hand-Pump operated bore-hole water AGC had provided them with had a strange oily taste suggesting that it was polluted, making most community members fear to drink it. At Aduaneyede, some (45%) community members were worried about the difficulty in getting their regular water supplies from the AGC-provided bore hole water at certain times due to problems associated with the operation of the device used in pumping the water from the ground. The water has to be pumped from the borehole into a Head Tank using an electrical device. Community members could then draw their household water directly from the tank. The problem was, any time there was power outage – a common phenomenon in the village – it was impossible to get water from the source when the head tank water was exhausted, creating 'artificial' water shortage in the village. There was also a general complaint that on many occasions, the water looked turbid and hence not considered potable enough for direct consumption, but repeated attempts to have AGC rectify the problem had proved futile. None (0%) of the respondents from Ampunyasi expressed satisfaction about the hand-operated borehole water provided for the community by AGC. According to them water from the bore hole could not be drunk and was only used for washing and cleaning due to the presence of a brownish oily substance on the surface of the water. For fear that it might be contaminated, they simply would not risk drinking water from the borehole. Again, all the respondents complained that food (yam, cassava, plantain, rice, etc.) turned dark brown in colour when cooked with water from the borehole. Due to the above problems, the entire village had been relying on a perennial stream (Aponapo Stream) for their cooking and drinking water supply.

In the RAL mining area, 60% of the interviewees from Dadease, and all (100%) respondents from each of the three remaining communities were satisfied with the alternative potable water (pump-operated borehole water) that RAL had provided for their communities. In the BGM mining area, all (100%) respondents in two communities (Tetrem and Bonteso) said they were happy with the quality and quantity of the potable water (pump-operated borehole water) BGM had provided for their community. However, at Mpatuom, only 40% of the respondents expressed satisfaction about the adequacy of the potable water BGM had provided their community with. None of the Jeninso respondents was satisfied with BGM's pump-operated borehole water. At both Mpatuom and Jeninso, most of the interviewees thought BGM needed to provide their communities with additional pump-operated bore hole water. According to them, the amount of water their communities required was far more than what was available to them as at the time of the survey.

While most of the respondents interviewed in the BGL mining area (Chuja – 90%; Odumasi – 100%; Kumsono – 65%) were satisfied with the alternative water BGL had provided their communities with (pump-operated borehole water), none of the Kwameniampa respondents expressed such satisfaction. According to the Kwameniampa respondents, the Wassa West District Assembly had provided the only pump-operated borehole water in the village. They complained that although they needed more potable water, BGL, whose mining operations had rendered their natural water sources unsuitable for drinking, had failed to provide them with the additional potable water they were in dire need of.

iii. *Provision of Clinics / Other Health Facilities*

In all 16 communities, none of the respondents included 'provision of clinics / other health facilities' in their list of perceived positive mining impacts. In the AGC mining area, despite AGC having established a hospital at Obuasi (which is reasonably close to all four communities), according to the respondents, its services were hardly used by 'ordinary' rural community members due to the high cost involved. Apart from community members working with AGC who received treatment at the hospital at highly subsidised costs, only the rich in society could afford the services there. Most community members had therefore been using the Government Hospitals at Obuasi and Akrokerri (a town 18 km from Obuasi) where health services were affordable. This assertion was found to be true during discussions with the Development Committees of the four communities interviewed in the AGC mining area.

iv. *Provision of Schools*

None of the respondents in the AGC and BGM mining areas made mention of 'provision of schools' as a positive mining impact. However, in the RAL and BGL mining areas, two communities in each mining area (Manso-Nkran & Koninase in the RAL mining area, and, Odumasi and Kwameniampa in the BGL mining area) indicated that their communities had been assisted by RAL and BGL respectively, in the construction of schools. Each of the communities considered this as a 'substantial benefit' of mining activities.

v. *Improvement in Roads / Road networks*

In the RAL mining area, with the exception of one community (Kaniago) where the respondents rated 'improvement in roads / road networks' by RAL as a 'major' beneficial impact of RAL's mining operations, all the interviewed communities in the area rated it a 'substantial benefit'. The overall rating of BGL's contribution to ‘improvement in roads / road networks’ in the Bogoso area as a ‘limited benefit’ accruing from RAL’s mining operations in the area pointed to one thing: most of the respondents did not know BGL had financially supported the Wassa West District Assembly in tarring the roads in the area. This lack of knowledge came to light during a meeting with senior staff of the Wassa West District Assembly and during discussions with the Village Development Committees in the area. In the AGC and BGM mining areas, none (0%) of the interviewees included ‘improvement in roads / road networks’ on their list of beneficial mining impacts on their communities.

vi. *Enhancement of Trade*

In the RAL, BGM and BGL mining areas, every community rated ‘enhancement of trade’ as a mining impact of ‘substantial benefit’ to community members. However, in the AGC mining area, perceptions differed from community to community. At Sansu (the community closest to the mine), ‘enhancement of trade’ as a result of AGC’s mining operations in the Obuasi area was rated a ‘major benefit’. At Aduaneyede (9 km from the mine), it was rated a ‘significant benefit’. At Ahansonyewodea (12 km from the mine) respondents described ‘enhancement of trade as a ‘substantial benefit’ derived from AGC’s mining operations in the Obuasi area. However, at Ampunyasi (18 km from the mine), the respondents perceived ‘enhancement of trade’ through AGC’s mining operations in the Obuasi area as a mining impact of ‘limited benefit’ to their community members.

6.4 **Negative Mining Impacts**

Community perceptions of the negative impacts of mining operations in the four mining areas are summarised in Table 6.4 and described in detail below. Some of the issues most members of the 16 communities complained about are illustrated with photos from the AGC mining area (Plates 1 – 5).

6.4.1 ***Air Pollution***

Air pollution was considered a 'severe' adverse mining impact in each of the 16 communities in the study area. In the AGC and BGL mining areas, the perception of severity of air pollution did not differ from community to community (all [100%] respondents in each community considered air pollution as a serious mining impact). However, in the RAL and BGM mining areas, the severity of air pollution was perceived to be more pronounced in the communities closest to the mines than those furthest away from the mines, as shown in Figures 6.4 and 6.5.

In all four mining areas, most complaints on air pollution centred on dust from ore processing activities and road dust generated by heavy-duty mine vehicles. In addition to this, smoke and excessive noise from blasting operations were also cited in the AGC and BGL mining areas. Respondents from Ahansonyewodea in the AGC mining area particularly complained about pungent smell in the air, which they suspected to be related to Sulphur Dioxide (SO_2) emissions from AGC's Sulphur Treatment Plant located at Pompora near Obuasi.

Table 6.4: Negative Mining Impacts as Perceived by the General Community in the Study Area

Mining Area	Communities	Distance from Mine (km)	Perception of Negative Mining Impacts (% Respondents)					
			Air Pollution	Water Pollution	Destruction of Farms / Farmlands	Destruction of Buildings / Other property	Difficulty in Fuelwood Acquisition	High Cost of Living
AGC Mining Area	Sansu	0.05	100	95	100	30	50	45
	Aduaneyede	9.00	100	75	100	35	30	60
	Ahansonyewodea	12.00	100	95	100	30	50	45
	Ampunyasi	18.00	100	70	100	30	20	55
	% Respondents (Average)		**100%**	**83.8%**	**100%**	**31.2%**	**37.5%**	**51.2%**
	Severity of Impact		**Severe Impact**	**Severe Impact**	**Severe Impact**	**Limited Impact**	**Limited Impact**	**Significant Impact**
RAL Mining Area	Manso-Nkran	0.85	100	90	100	15	5	35
	Koninase	3.20	100	100	100	15	5	50
	Dadease	4.50	65	95	100	5	0	75
	Kaniago	7.00	70	90	100	0	0	65
	% Respondents (Average)		**83.8%**	**93.8%**	**100%**	**8.8%**	**2.5%**	**56.2%**
	Severity of Impact		**Severe Impact**	**Severe Impact**	**Severe Impact**	**No Impact**	**No Impact**	**Significant Impact**
BGM Mining Area	Tetrem	0.50	100	100	100	0	0	60
	Bonteso	1.60	100	100	100	0	0	70
	Mpatuom	5.00	75	100	100	0	5	75
	Jeninso	7.50	65	100	100	0	0	70
	% Respondents (Average)		**85%**	**100%**	**100%**	**0%**	**1.2%**	**68.8%**
	Severity of Impact		**Severe Impact**	**Severe Impact**	**Severe Impact**	**No Impact**	**No Impact**	**High Impact**
BGL Mining Area	Chujah	0.03	100	90	100	55	0	15
	Odumasi	0.25	100	100	100	60	0	30
	Kumsono	2.50	100	80	100	30	0	20
	Kwameniampa	3.60	100	90	100	70	0	20
	% Respondents (Average)		**100%**	**90%**	**100%**	**53.8%**	**0%**	**21.2%**
	Severity of Impact		**Severe Impact**	**Severe Impact**	**Severe Impact**	**Significant Impact**	**No Impact**	**Limited Impact**

Plate 1: Residential Units at Sansu located less than 50 metres from AGC's Sansu Mine

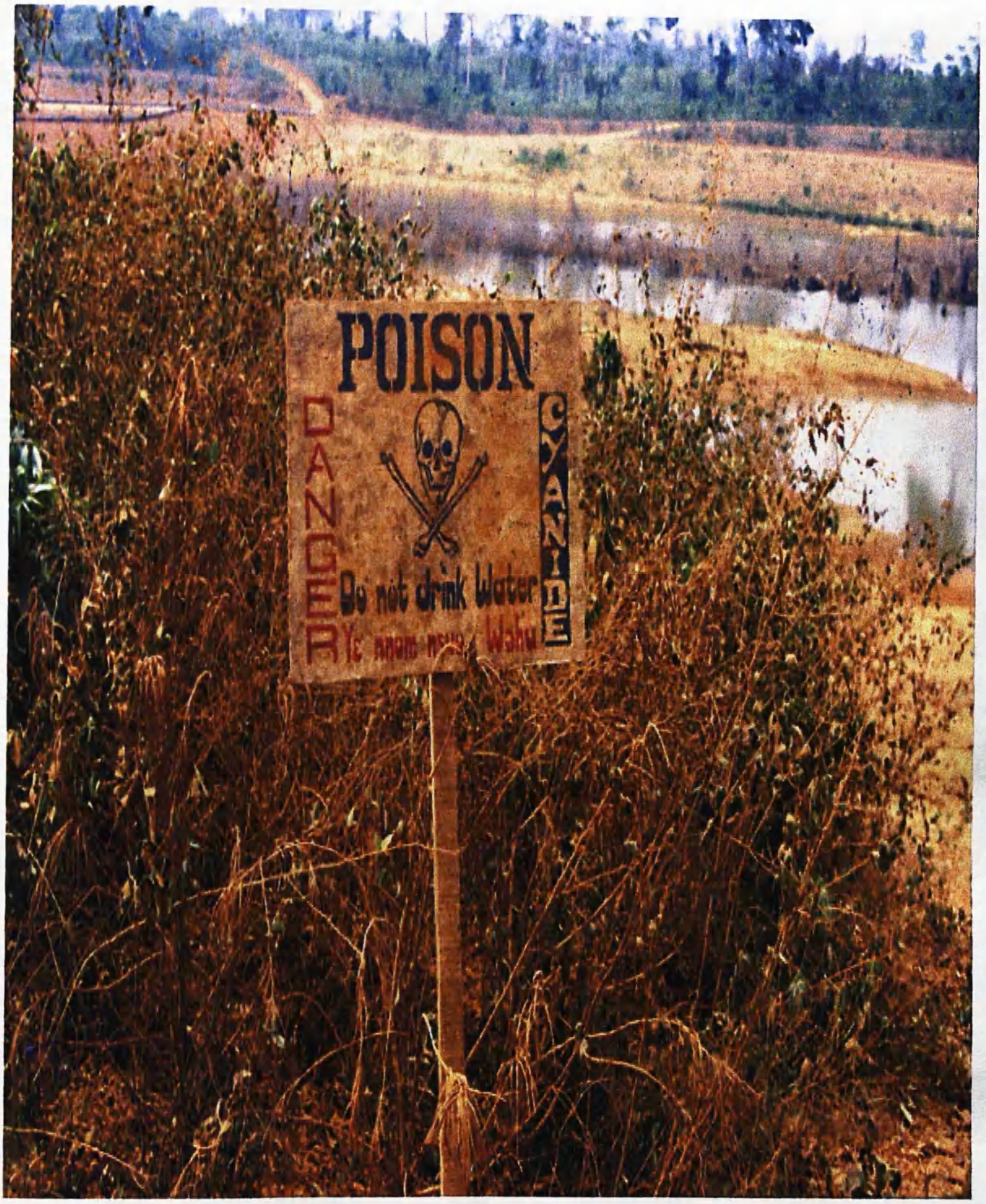

Plate 2: AGC-Mounted Signboard near a Stream in the Ahansonyewodea Area warning Local Communities against drinking water from the Cyanide-Poisoned Stream

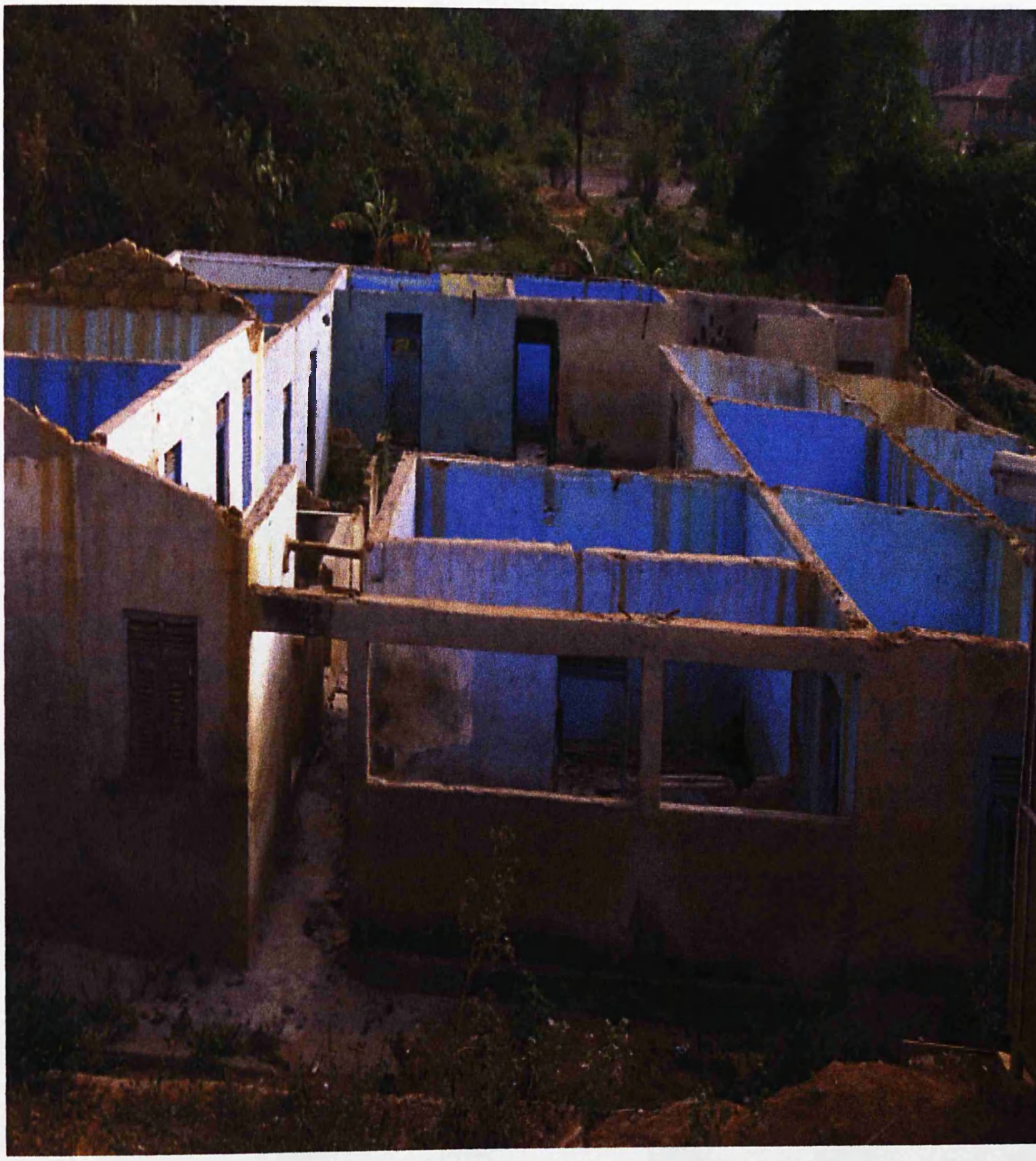

Plate 3: Collapsed Residential Building at Aduanyede (the result of Floods from the AGC Mining Area near Obuasi)

Plate 4: Soil Erosion & Degradation on Bare Steep Slopes (resulting from AGC's Mining Operations) near Ahansonyewodea in the Obuasi Area

Plate 5: Plantain Farm at Ahansonyewodea flooded by Waste Water from the AGC Mining Area near Obuasi

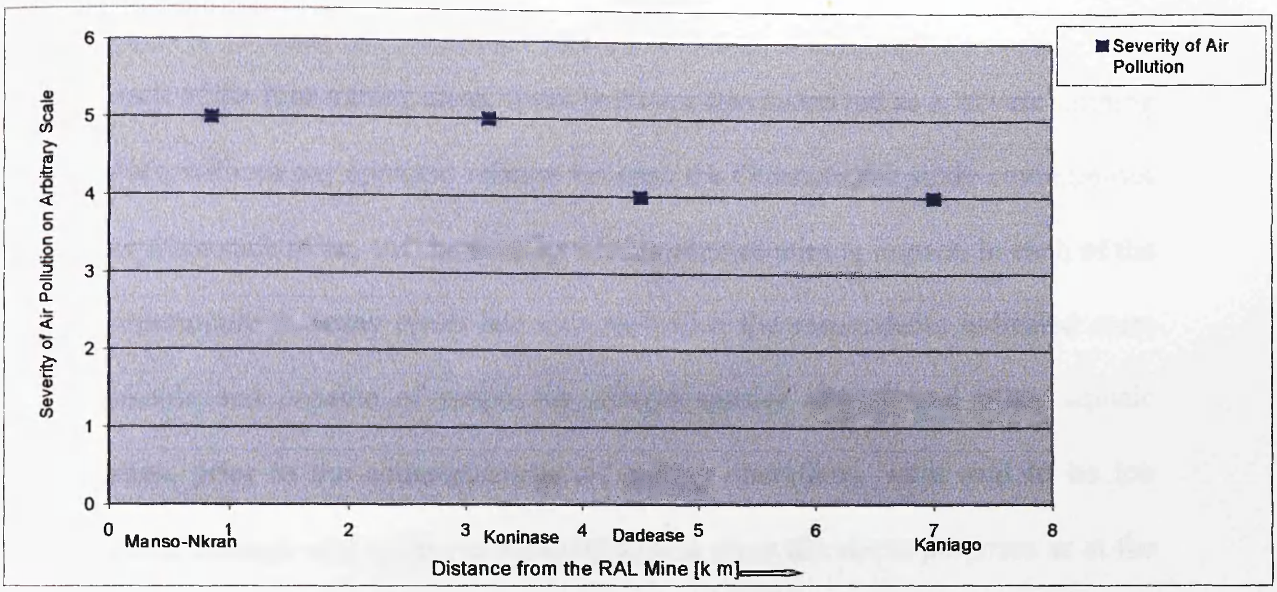

Figure 6.4: Graph showing Severity of Air Pollution at various Community Distances from the RAL Mine

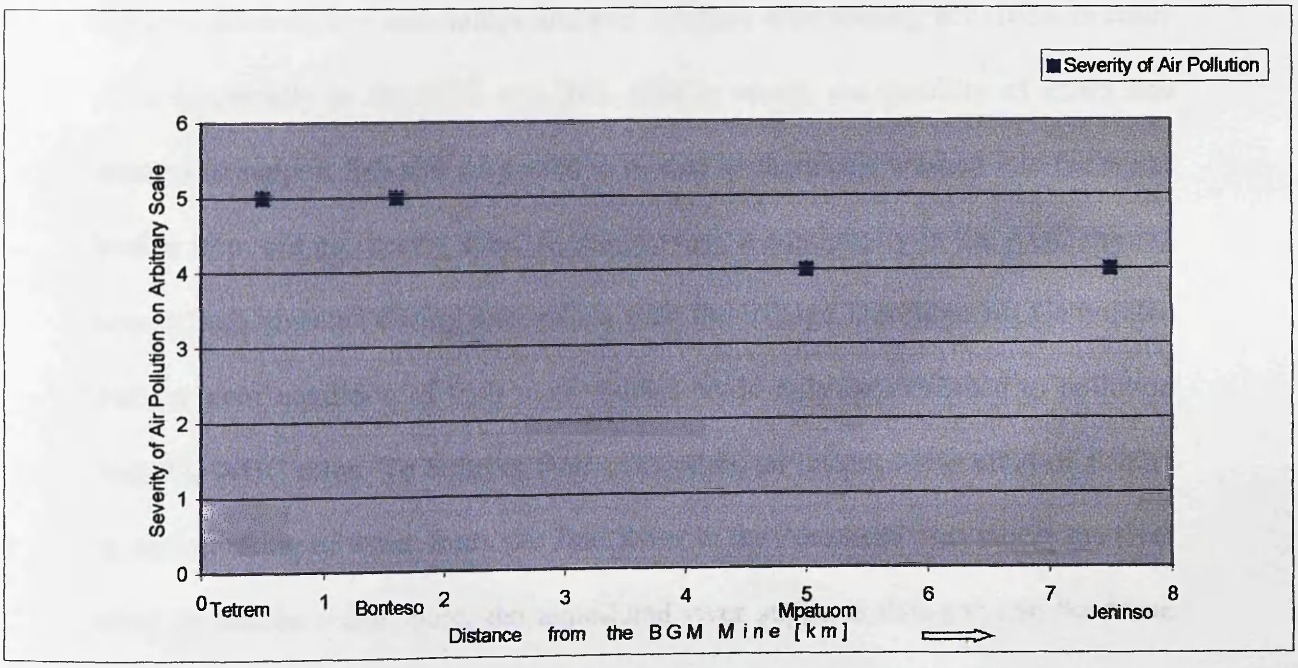

Figure 6.5: Graph showing Severity of Air Pollution at various community locations from the BGM Mine

6.4.2 *Water Pollution*

In each of the four mining areas, water pollution was perceived as a 'severe' mining impact, without any apparent relation between the distances the study communities were from each mine, and the severity of this adverse mining impact. In each of the 16 communities, many rivers and streams which the respondents indicated were drinkable and capable of supporting several species of fish and other aquatic animals prior to the commencement of mining operations, were said to be too polluted through mining operations to be able to serve the above purposes as at the time of the survey.

Most of the rivers and streams were described as 'dirty' by the respondents (apparently due to their turbid nature), and they attributed the condition to eroded material from mine waste dumps and soil left bare after mining activities. In some cases (especially in the AGC and BGL mining areas), the inability of rivers and streams to support fish was suspected to be due to chemicals washed into the water bodies from ore processing sites. At Ampunyasi, a community in the AGC mining area, it was revealed during discussions with the Village Development Committee that the poor condition of their water bodies could only be attributed to pollution from the AGC mine. To buttress their conviction, an instance was cited of fishing in, and drinking of water from, the Jimi River in the Akrokerri area where the river takes its source – that there, the unpolluted river supports fish and can be drunk without treatment by local residents. However, according to them, due to pollution from mine waste downstream, beginning from Obuasi, through Ampunyasi to the

Dunkwa area, sign boards had been erected along the river warning the public against drinking, swimming or fishing in the river.

In the AGC and BGM mining areas, many rivers and streams, which were said to be perennial prior to the commencement of mining operations, had silted up at the time of the field survey. It was alleged that this was the result of eroded soil washed from the mining areas into the water bodies over several years.

6.4.3 *Destruction of Farms / Farmlands*

Like water pollution, each of the 16 communities rated 'Destruction of farms / farmlands' a 'severe' mining impact. In fact, in each community, irrespective of the mining area, all (100%) respondents perceived it as a very serious adverse mining impact. In all four mining areas, the respondents complained about the destruction of farms and farmlands to make way for surface mining activities without adequate compensation paid to community members adversely affected in the process. Again, it was disclosed that the mining companies paid no compensation on farmlands without crops on them at the time of land clearance for mining activities.

In the AGC mining area, in addition to the above complaints, other issues were raised. For instance, at a meeting with the Village Development Committee of Sansu, it was revealed that in many farming areas in the village, crop production levels had fallen as a result of soil pollution by cyanide residue (referred to as 'semet' locally). According to them, 'wherever wastewater from the mine containing 'semet' passes, crops there die or do not do well.' Some respondents from Aduaneyede who farm outside but close to the AGC concession disclosed that they could 'confidently' consume or sell vegetables (especially cocoyam leaves) on their farms only at the peak of the rainy season, since, during the dry season, they turned dark-brown in colour resulting from a combination of dust, smoke and chemical pollutants blown onto them from the AGC mine. Many interviewees in the village also complained about reduction in crop yields as a result of soil pollution by cyanide residue ('semet') carried onto their farms by wastewater from the AGC ore processing area. A farmer at Ahansonyewodea disclosed that in June 1998, he and 2 other farmers lost most of their vegetables when they (vegetables) got buried in mud washed onto their farms by high-velocity rain water (runoff) from adjacent steep hills left bare after AGC's surface mining activities.

6.4.4 *Destruction of Buildings / Other Property*

The above impact was rated 'significant' by respondents in the BGL mining area, but was perceived as having a 'limited impact' by respondents in the AGC mining area. In the RAL and BGM mining areas, it was perceived that mining activities had 'no impact' on buildings and other property of their community members. This rating by the respondents in the BGM mining area was not surprising, given the fact that BGM's operations exclude blasting, the main mining activity blamed for the destruction of buildings in the AGC and BGL mining areas. The 'no impact' rating of the above mining impact by respondents in the RAL mining area, seemed to lend credence to RAL's assertion that adequate measures were in place at its Manso-Nkran gold mine, to minimise the effects of its blasting activities.

In each of the villages in the AGC mining area, the respondents thought AGC's activities had 'limited impact' on buildings and other property of community members irrespective of the location of the communities from the AGC mine. The major complaint in all four communities was development of cracks in buildings, and in some cases, destruction of whole buildings, following AGC's blasting operations. At Aduaneyede, it was disclosed that three houses had collapsed after being completely flooded with high-velocity sediment- and debris- laden runoff from bare hills in the AGC mining concession. Two houses had collapsed at Ahansonyewodea in previous years under similar circumstances. While the mining company did not pay any compensation to people whose buildings had developed cracks as a result of mining operations, people who completely lost their houses to mining-related floods felt they were not adequately compensated by AGC. For instance, at Ahansonyewodea, a man whose 14-roomed house was completely destroyed by floods from AGC's mine site in 1995 revealed he received a compensation of 2, 700, 000 cedis (about $1450 at 1995 exchange rates) from AGC. According to him, this amount was not enough to put up even a 6-bedroomed house.

In the BGL mining area the above mining impact was rated 'significant' overall. However, perception of the severity of this impact differed from community to community (Figure 6.6).

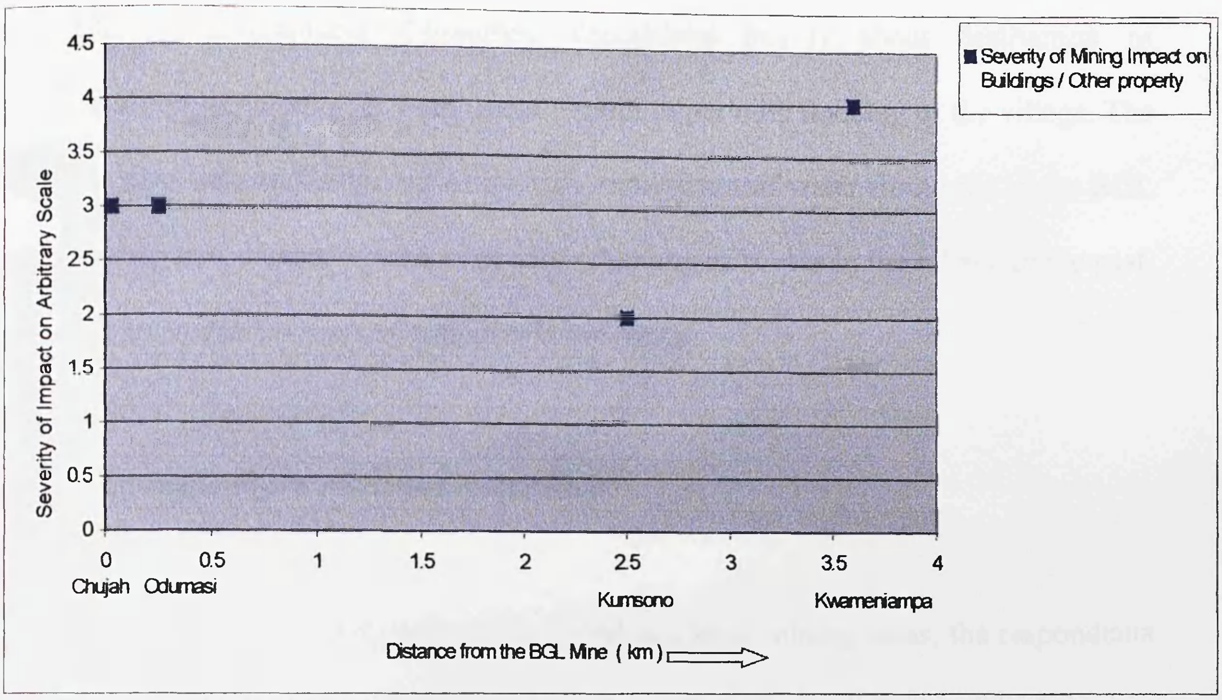

Figure 6.6: Graph showing Severity of Mining Impact on Buildings / Other Property at Various Community Distances from the BGL Mine

As shown in Figure 6.6, the two communities closest to the BGL mine (Chujah and Odumasi) indicated that the company's operations had a 'significant impact' on buildings / other property of their community members. In the next village (Kumsono), the company's operations were said to have had only a 'limited impact' on buildings / other property of community members. This was not surprising, given that in all three villages, the respondents complained mainly about blasting-induced cracks to buildings of some community members. 'Surprisingly', it was only at Kwameniampa (the furthest community from the BGL mine) that the respondents perceived mining-related destruction of buildings / other property of community members as a 'high impact'. It must however be pointed out that unlike the other three communities where the interviewees were concerned about blasting-related cracks to buildings, at Kwameniampa, the respondents, together with the

Village Development Committee, complained mainly about destruction of buildings of community members as a result of periodic flooding of the village. The flooding was said to be caused by high velocity runoff water from hills in the BGL mining area. Instances were cited about flooding of houses in the village in the past, rendering their occupants temporarily homeless.

6.4.5 ***Difficulty in Fuelwood Acquisition***

As shown in Table 6.4, in the RAL, BGM and BGL mining areas, the respondents indicated that mining activities had 'no impact' on the availability of fuelwood in their respective communities. The responses did not differ from community to community, irrespective of the distance of the community from a particular mine. It was however disclosed in all the communities that over the years, distances covered to have access to adequate firewood sources had generally been increasing.

In the AGC mining area, it was only at Ampunyasi (the furthest community from the AGC mine) that the respondents thought AGC's mining operations had 'no impact' on fuelwood acquisition by community members. In two of the four study communities (Sansu and Ahansonyewodea) community members perceived that mining operations had a 'significant impact' on fuelwood acquisition by community members. This was to be expected, given the number of years and the scale of AGC's operations in the Obuasi area as previously explained. However, it was initially difficult to understand the overall rating of this impact as 'significant' at Ahansonyewodea (12 km from the AGC mine) when compared to its 'limited

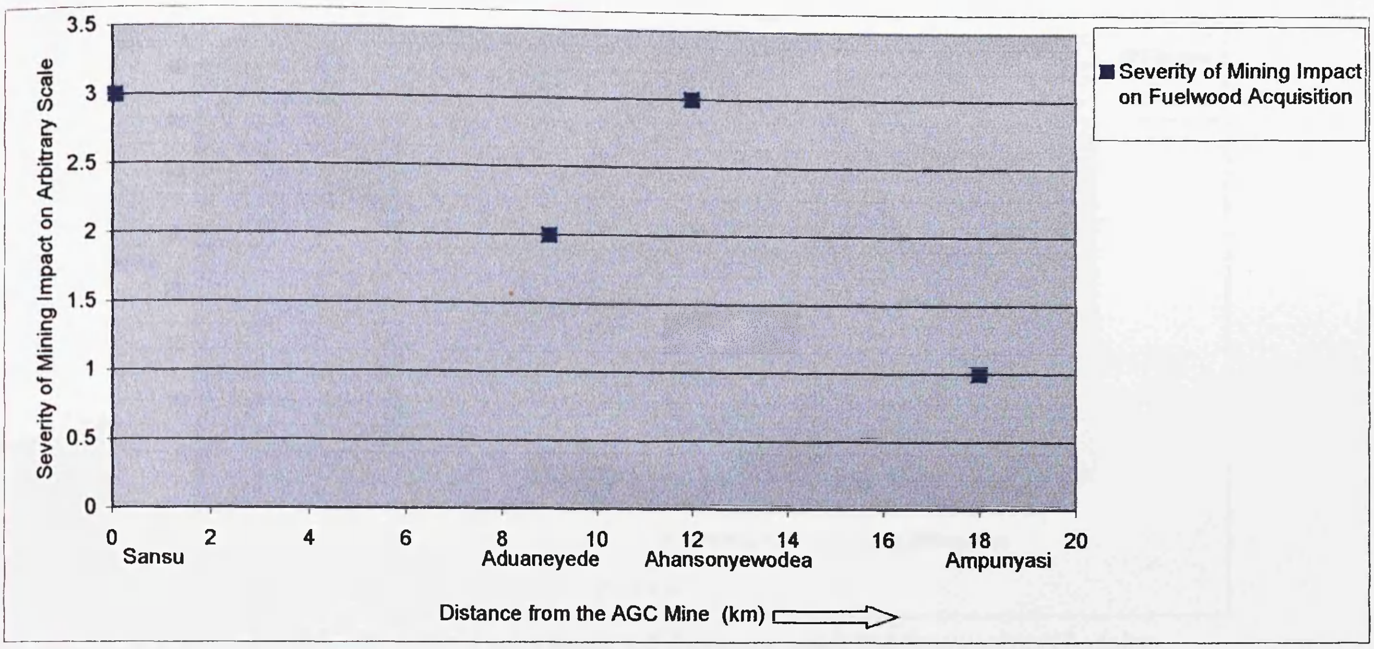

Figure 6.7: Graph showing Severity of Fuelwood Scarcity at various Community Distances from the AGC Mine

impact' rating by respondents of Aduanyede [9 km from the mine] (see Figure 6.7). This 'unusual' phenomenon was however explained by respondents who were mature enough in the 1960's, and also, during discussions with the Ahansonyewodea Village Development Committee. According to them, in the 1960's, AGC bought several hectares of the community's forested land outside the concession and established teak plantations on it, to generate timber for mining operations at the company's then underground mine at Obuasi. This had therefore compelled many community members to fetch firewood from forested land belonging to neighbouring communities for several years.

One observation made was the influence of occupation on the perception of mining-related fuelwood scarcity in the study area. For instance, with the exception of the BGL mining area where none of the traders or farmers interviewed compalined about fuelwood shortage, in each of the mining areas, a higher proportion of farmers complained about fuelwood shortage than traders (Figure 6.8).

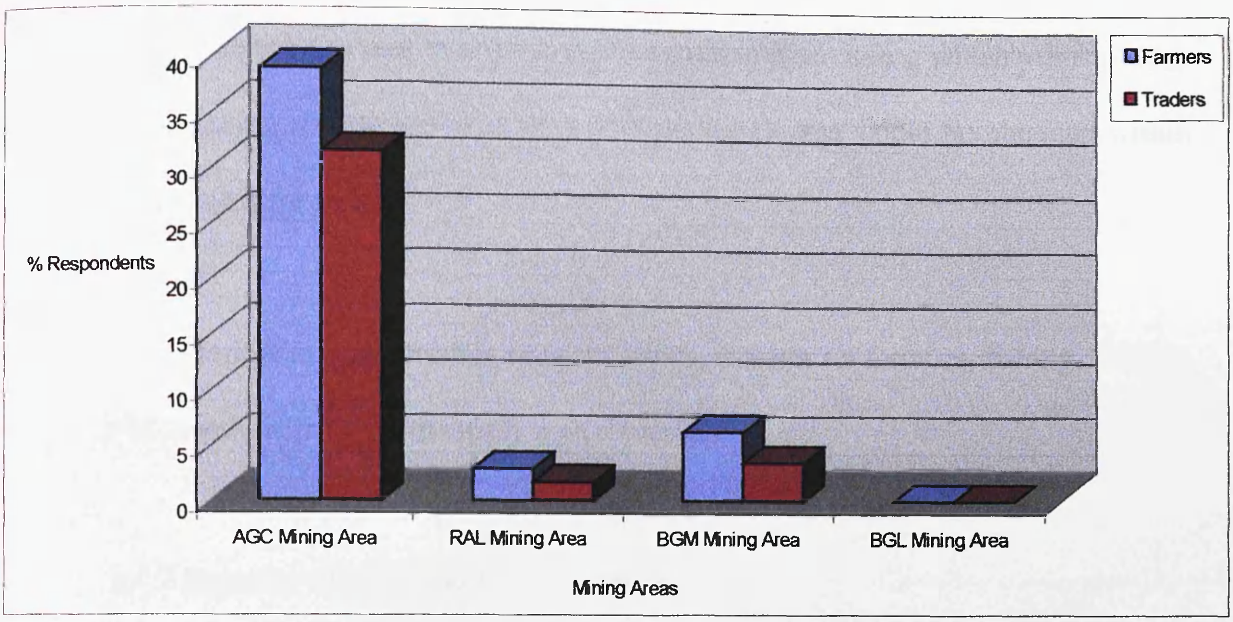

Figure 6.8: Graph showing Percentage of Farmers and Traders acknowledging Fuelwood Acquisition Problems in the four Mining Areas

6.4.6 *Impact on Cost of Living*

With the exception of the BGL mining area where mining was said to have had only a 'limited impact' on the cost of living, a rise in the cost of living as a result of mining activities was a concern in all the mining areas. While high cost of living was considered a 'significant' mining impact in the AGC and RAL mining areas, the respondents in the BGM mining area rated it a 'high impact'. Most of the complaints about the rising cost of living centred on the rising cost of foodstuffs and accommodation. This was attributed to competition from rich mine workers who had contributed in pushing up the cost of these basic necessities, to the detriment of poor subsistence farmers in their communities. In addition to the above issues, in the RAL mining area, another concern was raised. According to the respondents, they had been denied access to the unmined forest area at the periphery of RAL's concession, to search for mushrooms, game, poles, roofing materials and firewood. According to them, due to this denial, community members were compelled to trek long distances in search of these items, which prior to RAL commencing mining activities in the Manso-Nkran area, could be obtained within easy access for free.

In the following sections, the negative mining impacts on farming, fishing, hunting and wood gathering in the study area are outlined.

6.4.7 *Negative Mining Impact on Farming*

Table 6.5 summarises the negative impact of mining operations on crop production levels, as reported by farmers (10 farmers per community) in the study area.

As can be seen from Figure 6.9, it was only in the BGM mining area that the proportion of farmers who complained about 'very high' mining-induced reduction in their crop production levels, did not vary between farmers from the community closest to the reference mine, and those from the community furthest from the mine. In the other mining areas, more farmers from the 'closest' communities complained about 'very high' (75 – 100%) reductions in their annual crop production levels than farmers from the 'furthest' communities. As shown in Figure 6.10, it was only in the BGM mining area that the proportion of farmers from the 'closest' community, as of the 'furthest' community, reported 'negligible – very low' mining-related reduction in their annual crop production levels. In each of the remaining mining areas, a greater proportion of farmers from the 'furthest' communities reported 'negligible – very low' reductions in their annual crop production levels than those from the 'closest' communities.

Table 6.5: Negative Mining Impact on Estimated Crop Production Levels as reported by Farmers in the Study Area

Mining Area	Communities	Fall in Annual Crop Production Levels			
		Negligible – Very Low (0 – 25% fall)	Low – Fairly high (25 – 50% fall)	High (50 – 75% fall)	Very High (75 – 100% fall)
AGC Mining Area	Sansu	0	0	20	80
	Aduaneyede	30	0	20	50
	Ahansonyewodea	40	20	10	30
	Ampunyasi	40	10	10	40
RAL Mining Area	Manso-Nkran	30	0	20	50
	Koninase	30	20	20	30
	Dadease	40	30	0	30
	Kaniago	40	40	10	10
BGM Mining Area	Tetrem	30	30	10	30
	Bonteso	30	20	20	30
	Mpatuom	20	30	20	40
	Jeninso	30	10	30	30
BGL Mining Area	Chujah	40	10	10	40
	Odumasi	30	20	20	30
	Kumsono	40	10	10	40
	Kwameniampa	50	30	10	10

* Values indicate % respondents

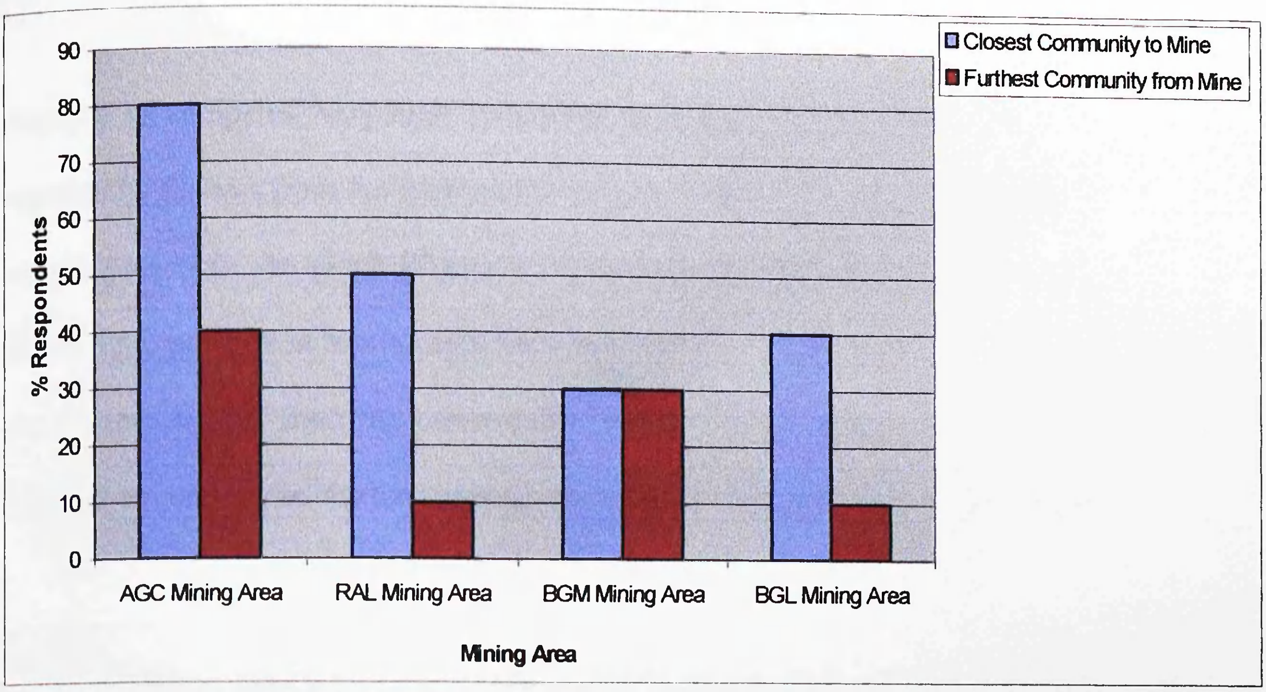

Figure 6.9: Negative Mining Impact on Crop Production Levels as indicated by Farmers reporting 'Very High' Reduction in their Annual Crop Production Levels in Communities 'Closest to' and 'Furthest from' each of the four Mines in the Study Area

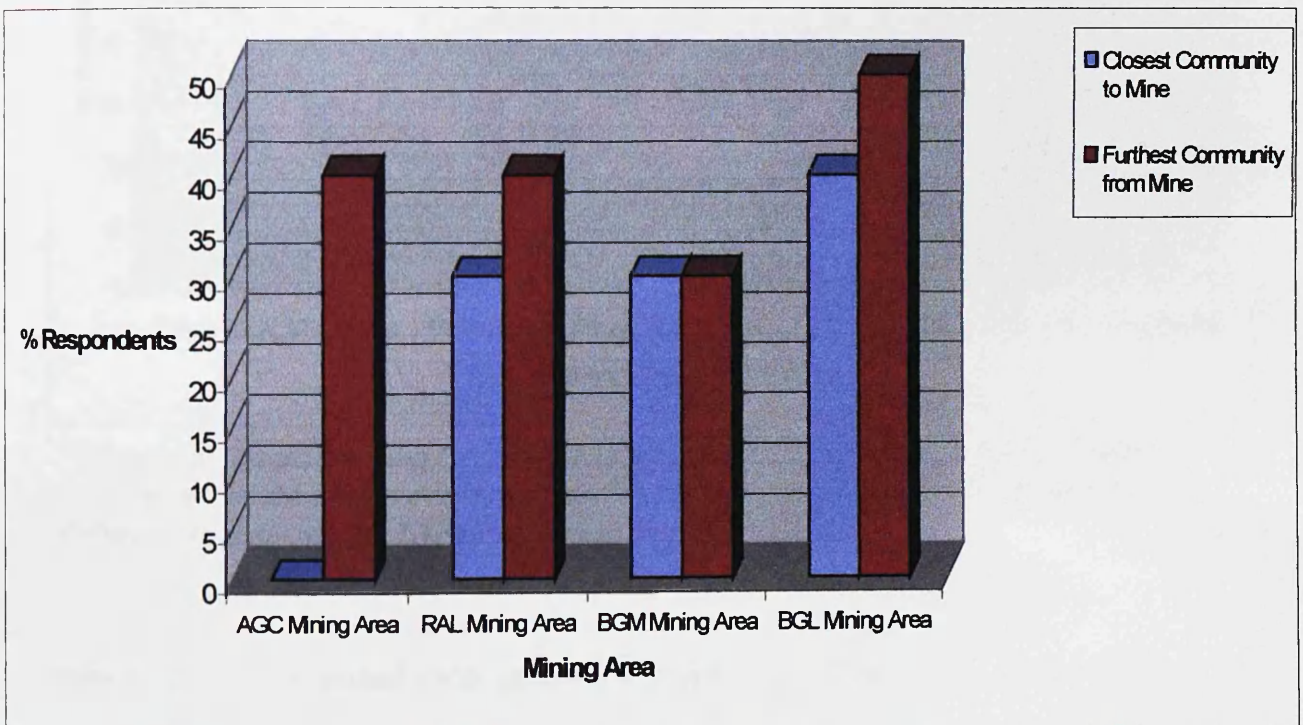

Figure 6.10: Negative Mining Impact on Crop Production Levels as indicated by Farmers reporting 'Negligible – Very Low Reduction in their Annual Crop Production Levels in Communities 'Closest to' and Furthest from' each of the four Mines in the Study Area

Figure 6.11 compares 'very high' reductions in annual crop production levels, as reported by farmers from the communities closest to the mines in the study area. It can be seen from the graph (Figure 6.11) that more complaints on reduction in annual crop production levels came from Sansu in the AGC mining area (80% of the 10 respondents from the community). While 50% of respondents from the 'closest' community in the RAL mining area (Manso-Nkran) reported 'very high'

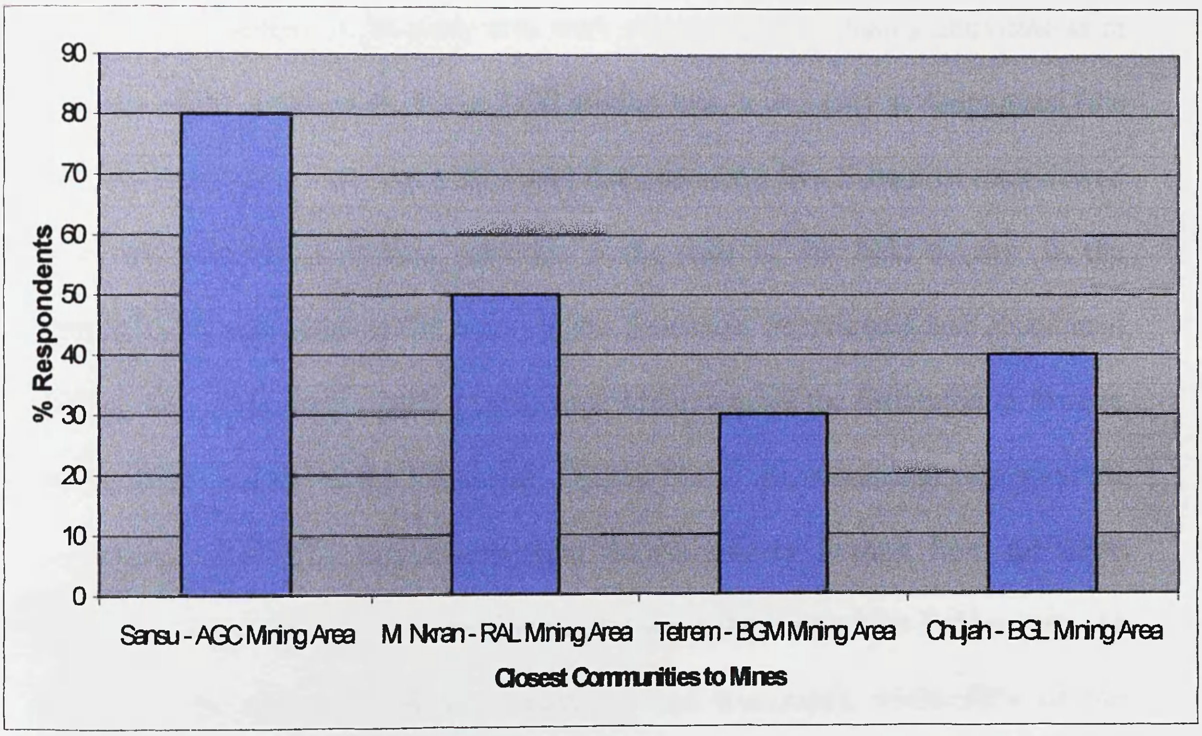

Figure 6.11: Graph showing Percentage of Respondents from Communities Closest to the mines in the study area reporting 'Very High' (75 – 100%) mining-related Reduction in their Annual Crop Production Levels

reductions in their annual crop production levels, only 30% of the interviewed farmers from Tetrem reported 75 – 100% fall in their annual crop production levels as a result of mining operations. In the BGL mining area, 40% of the farmers from Chujah indicated having experienced 'very high' mining-induced reduction in their annual crop production levels.

The reasons given for the general decline in annual crop production levels were similar in all four mining areas, viz: (i) Direct use of portions of farms or whole farms for mining / mining activities and / or (ii) Destruction of crops as a result of mining- induced flooding and / or chemical pollution.

6.4.8 *Negative Mining Impact on Fishing Activities in the Study Area*

Very few fishermen in the study area were still engaged in fishing activities as at the time of the field survey. In the AGC mining area, it was only at Ampunyasi (the furthest community from the AGC mine) that one of the five fishermen interviewed was still engaged in fishing activities at the time of the field survey. In the remaining communities in the area, all the fishermen interviewed had abandoned fishing altogether. In the RAL mining area, while none of the fishermen in the two communities closest to the RAL mine (Manso-Nkran and Koninase) was involved in fishing, all (100%) respondents from the community furthest from the mine (Kaniago) were still engaged in fishing activities at the time of the field survey. At Dadease (the community between Kaniago and Koninase), while 40% of the interviewees were still involved in fishing activities, 60% of them had given up fishing. All the fishermen interviewed in the BGM and BGL mining areas indicated they had abandoned fishing altogether.

All the interviewees were of the view that there had been a general reduction in fish catch / numbers in their community over the years. When asked to list three most likely causes of decreasing fish catch none of the respondents included ‘overfishing’ in their list. In fact, most of them listed water turbidity, flooding and chemical pollution. These are briefly described in the sections below.

i. *Water Turbidity*

Turbidity of rivers and streams was perceived to have a ‘severe impact’ on fish populations in the water bodies in all the communities. The problem was linked to eroded soil from devegetated areas and waste dumps at the mine sites carried into the water bodies by runoff water.

ii. *Flooding*

In the AGC and RAL mining areas, flooding was considered to have a ‘high impact’ on fish populations. However, in the BGM and BGL mining areas, flooding was perceived as having a ‘severe impact’ on fish populations. In all the mining areas, it was alleged that extensive clearance of vegetation for mining activities had led to increased flooding in low-lying areas during the rains. It was believed that large quantities of sediment-laden water that enters the rivers and streams during the floods had devastating effects on the survival of fish in the water bodies.

iii. *Low Water Levels*

Low water levels in rivers and streams were considered to have only a ‘limited impact’ on fish by respondents in the AGC and RAL mining areas, but perceived to have ‘no impact’ on fish numbers by respondents in the BGL mining area. It was only in the BGM mining area that the respondents felt it had a ‘significant impact’ on fish populations in their rivers and streams. It was generally thought that mining-induced sediment loading in water bodies in the study area during the rains lead to lowering of the water levels in most of the streams in the region. Some streams completely dry out at the peak of the dry season, leading to fish deaths.

iv. *Chemical Pollution*

Chemical pollution of water bodies was perceived to have a 'severe impact' on fish in the AGC and RAL mining areas, and, a 'high impact' on fish in the RAL mining area. Chemical residues washed into the water bodies from ore processing sites of the mines were blamed for the death of fish in the rivers and streams in these mining areas.

The perception of mining-related chemical pollution as contributing 'significantly' to fish deaths in the BGM mining area was a bit puzzling, given the fact that no chemicals are used throughout BGM's mining operations.

6.4.9 *Negative Mining Impact on Hunting Activities in the Study Area*

Many of the 80 hunters (5 hunters per community) interviewed in the study area had given up hunting as a result of the difficulty in sighting game. It was generally perceived that there had been a decline in game numbers in the study area over the years. However, none of them included 'overhunting', 'logging-related devegetation' or 'bushfires' in their list of 3 most likely causes of the trend. Every respondent blamed mining-related devegetation and noise for the reduction in game animal numbers in their respective communities over the years. This was irrespective of the community they lived in or the mining area in question. Although some of the respondents thought farming activities (and the consequent loss of wild animal habitats) were also to blame for the decline in game animal numbers in their communities, it was only in the AGC mining area that farming was perceived to have a 'high impact' on game animal populations. In all the other mining areas, farming-related devegetation was perceived to have only a 'limited' impact on the populations of wild animals in the various communities.

6.4.10 ***Impact of Mining Operations on Firewood Acquisition in the Study Area***

Table 6.6 summarises the responses of the 160 housewives (10 per community) in the study area with regard to how their household firewood was obtained. The proportion of housewives whose energy for household cooking was from a source other than firewood is also shown in the table. In the AGC mining area, it was only at Ampunyasi (the furthest community from the mine) that most (70%) of the housewives interviewed indicated they acquired their household firewood requirement directly from the bush.

Forty percent of the respondents from Sansu (the closest community to the AGC mine) said they fetched their firewood requirements directly from the bush. However, in each of the remaining two communities in the area (Aduaneyede and Ahansonyewodea), half of the respondents indicated they had been obtaining their household firewood requirement directly from the bush. Some of the respondents (40% at Sansu; 30% at Aduaneyede and Ampunyasi; and 10% at Ahansonyewodea) had been purchasing firewood from other members of their respective communities. The respondents who neither fetched nor purchased firewood indicated they had been using other sources of fuel (mainly charcoal and kerosene-fuelled stoves) for

Table 6.6: Means of Firewood Acquisition by Housewives in the Study Area

Mining Area	Communities	**Means of Firewood Acquisition**		
		Fetched (bush)	Purchased	Charcoal or Kerosene-fuelled Stove used
AGC Mining Area	Sansu	40	40	20
	Aduaneyede	50	30	20
	Ahansonyewodea	50	10	40
	Ampunyasi	70	30	Not Applicable
RAL Mining Area	Manso-Nkran	50	50	Not Applicable
	Koninase	70	30	Not Applicable
	Dadease	70	30	Not Applicable
	Kaniago	80	20	Not Applicable
BGM Mining Area	Tetrem	70	30	Not Applicable
	Bonteso	70	30	Not Applicable
	Mpatuom	80	20	Not Applicable
	Jeninso	80	20	Not Applicable
BGL Mining Area	Chujah	70	30	Not Applicable
	Odumasi	80	20	Not Applicable
	Kumsono	80	20	Not Applicable
	Kwameniampa	70	30	Not Applicable

* Values indicate % Respondents

household cooking.

Most of the housewives interviewed in the RAL mining area (Manso-Nkran – 50%; Koninase and Dadease – 70%; Kaniago – 80%) indicated they had been obtaining their firewood requirements directly from the bush. However, some of the housewives (Manso-Nkran – 50%; Koninase and Dadease – 30%; Kaniago – 20%) indicated they had been buying their firewood requirements from other members of the community. None of the interviewees used any other source of fuel for household cooking apart from firewood. Similarly, most of the housewives interviewed in the BGM mining area (Tetrem and Bonteso – 70%; Mpatuom and Jeninso – 80%) had been obtaining their household firewood requirements directly from the bush. The remaining interviewed housewives (Tetrem and Bonteso – 30%; Mpatuom and Jeninso – 20%) had been purchasing their firewood from other members of their respective communities. In the BGL mining area, 70% of the Chujah and Kwameniampa respondents, and 80% of the Odumasi and Kumsono respondents said they had been obtaining their household firewood requirement directly from the bush. The remaining housewives interviewed in the area (Chujah and Kwamenimpa – 30%; Odumasi and Kumsono – 20%) had been purchasing firewood from other members of their communities.

In all the mining areas, the housewives who had been fetching their firewood requirements directly from the bush reported a gradual increase in the distance covered to reach their firewood sources over the years. None of the interviewees blamed the problem on logging-related devegetation, bushfires or excessive wood gathering. The sections below outline the trends in the distances covered by the 'firewood-fetching' housewives in the various mining areas to reach their sources of firewood over the years. In these sections, 'housewives' refers to 'firewood-fetching' housewives in the study area.

i. *AGC Mining Area*

As shown in Figure 6.12, between 5 and 10 years prior to the survey, most of the housewives interviewed in the AGC mining area (Sansu – 75%; Aduaneyede – 80%; Ahansonyewodea – 60%; Ampunyasi – 100%) used to walk less than 1 km to reach their source of firewood. During the same period (5 – 10 years 'ago'), 25% of the Sansu housewives, 40% of the Aduaneyde housewives, and 20% of the Ahansonyewodea housewives interviewed indicated they had to trek between 1 – 5 km to reach their firewood sources. In all four villages none of the housewives interviewed had to travel beyond 5 km in search of firewood during the period.

Between 1 and 5 years prior to the survey, apart from Ampunyasi where some (43%) of the respondents said they covered less than 1 km to reach their source of firewood, most of the respondents (Sansu – 75%; Aduaneyede and Ahansonyewodea – 40%; Ampunyasi – 57%) said they had to trek between 1 – 5 km to reach their source of household firewood. During the same period, 25% of the Sansu housewives and 60% of the Aduaneyede and Ahansonyewodea housewives interviewed indicated they had to travel between 5 – 10 km to be able to obtain adequate firewood for household cooking.

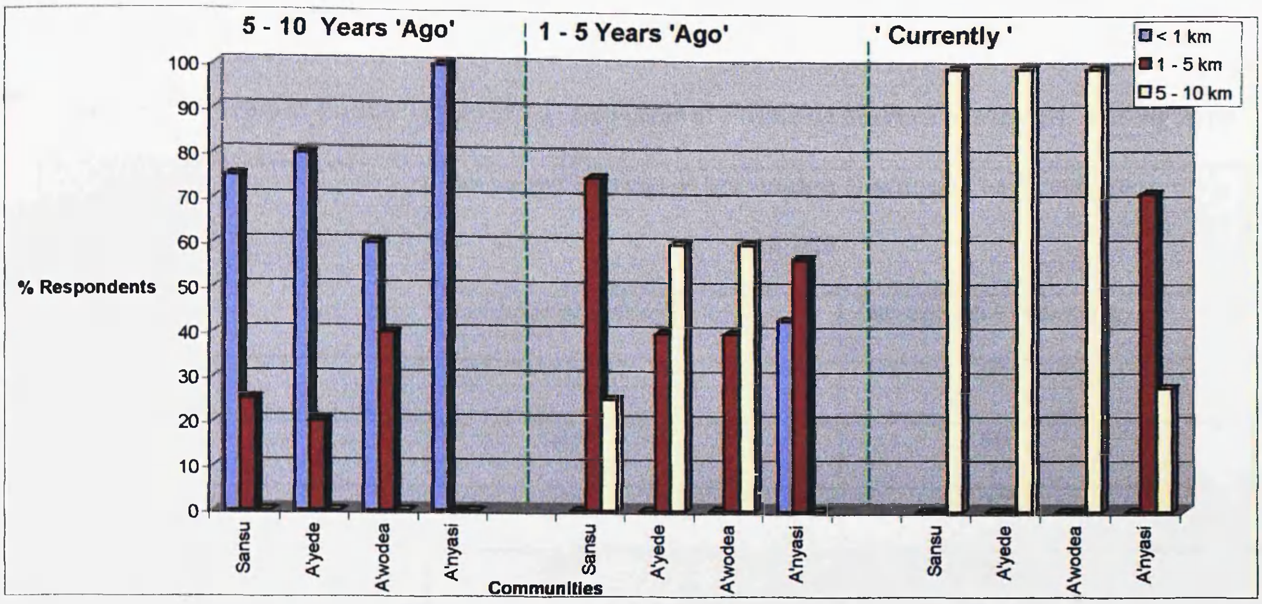

Figure 6.12: Distances Covered by Housewives in the AGC Mining Area to Fetch Firewood over time

At the time of the survey ('currently'), none of the interviewees could obtain enough firewood less than 1 km from their respective communities. Most (72%) of the Ampunyasi respondents said they could obtain their firewood requirements between 1 – 5 km from the village as at the time of the survey. However, none of the respondents from the other communities could obtain adequate firewood by trekking 1 – 5 km from their communities during the 'current' period. All (100%) respondents from Sansu, Aduaneyede and Ahansonyewodea, and 28% of the Ampunyasi respondents said they had to travel between 5 – 10 km to reach their sources of firewood at the time of the survey. When asked about the potential causes of increasing distances to firewood sources over the years (see Table 6.7), in each community, all the housewives interviewed attributed the trend to mining-related devegetation. While at Sansu and Aduaneyede 80% of the housewives thought farming-related devegetation could also be blamed for the difficulty in having access to adequate supply of firewood, only 30% of the Ahansonyewodea and Ampunyasi respondents thought this was the case.

Table 6.7: Perceived Causes of Increasing Distances to Firewood Sources in the AGC Mining Area

Communities	Perceived causes of Increasing Distances to Firewood Sources	
	Devegetation (mining)	Devegetation (farming)
Sansu	100	80
Aduaneyede	100	80
Ahansonyewodea	100	30
Ampunyasi	100	30

* Values indicate % Respondents

ii. *RAL Mining Area*

As shown in Figure 6.13, in each of the communities in the RAL mining area, all (100%) housewives interviewed reported that between 5 – 10 years prior to the survey, they used to walk less than 1 km to reach their source of firewoood. None of the interviewees had to travel beyond 1 km to obtain firewood during that period. However, 1 – 5 years 'ago', apart from Dadease where 57% of the interviewed housewives said they walked less than 1 km to reach their source of firewood, in all the communities, the respondents indicated they had to trek between 1 – 5 km to reach their firewood sources. During that period, many of the respondents (Manso-Nkran – 100%; Koninase – 100%; Dadease – 43%; Kaniago – 100%) reported trekking between 1 km and 5 km before obtaining adequate firewood for household cooking. As at the time of the survey ('currently'), 80% of the Manso-Nkran, housewives, 57% of the Koninase and Dadease housewives, and, 38% of the Kaniago housewives interviewed, said they had to trek up to 5 km to gain access to adequate quantities of firewood. During the same period, some of those interviewed (Manso-Nkran – 20%; Koninase and Dadease – 43%; Kaniago –

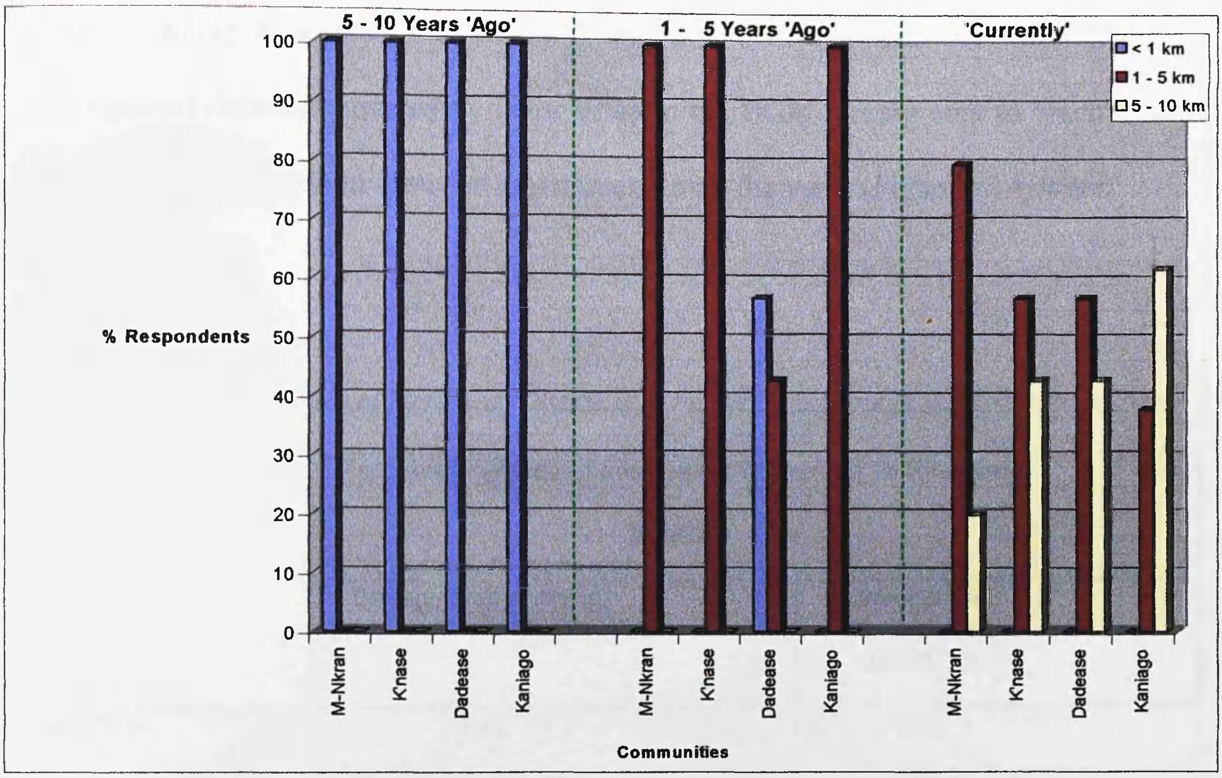

Figure 6.13: Distances Covered by Housewives in the RAL Mining Area to Fetch Firewood over time

62%) indicated they had to trek between 5 – 10 km to be able to obtain adequate firewood for household cooking.

As shown in Table 6.8, while all (100%) respondents in the RAL mining area blamed mining-related devegetation for the gradual depletion of firewood in their respective communities over the years, some of them (Manso-Nkran and Koninase – 50%; Dadease – 70%; Kaniago – 60%) also thought devegetation resulting from farming activities could also be blamed for the general increasing distances to firewood sources in their respective communities over the years.

iii. *BGM Mining Area*

The reported distances covered by housewives in the BGM mining area to reach their sources of household firewood requirements over the years (Figure 6.14) were as follows:

Table 6.8: Perceived causes of Increasing Distances to Firewood Sources in the RAL Mining Area

Communities	**Perceived causes of Increasing Distances to Firewood Sources**	
	Devegetation (mining)	Devegetation (farming)
Manso-Nkran	100	50
Koninase	100	50
Dadease	100	70
Kaniago	100	60

* Values indicate % Respondents

- 5 – 10 years prior to the survey, all (100%) respondents in the area walked less than 1 km to reach their firewood sources, with none of them travelling beyond 1 km to reach their firewood sources during that period

- 1 – 5 years 'ago', none (0%) of the respondents from Tetrem, 29% of the Bonteso respondents, 75% of the Mpatuom respondents and 88% of the housewives from Jeninso indicated they still walked less than 1 km to reach their firewood sources. Many of the respondents (Tetrem – 75%; Bonteso – 71%; Mpatuom – 25%; Jeninso – 12%) said 1 – 5 years 'ago' they had to trek between 1 – 5 km to reach their firewood sources. While some (25%) of the housewives from Tetrem said they had to travel between 5 – 10 km in search of firewood 1 – 5 years 'ago', none of the interviewees from the other communities had to travel this distance to reach their firewood sources 1 – 5 years prior to the survey

- At the time of the survey, none of the interviewees reported they walked less than 1 km to reach their firewood sources. Some of the housewives (Tetrem – 65%; Bonteso – 75%; Mpatuom – 50%; Jeninso – 72%) said during the survey period, they could reach their firewood sources only after trekking between 1 – 5 km away from their respective communities. Other respondents (Tetrem – 35%; Bonteso – 25%; Mpatuom – 50%; Jeninso – 38%) indicated they had to travel between 5 – 10 km to reach their firewood sources during the survey period

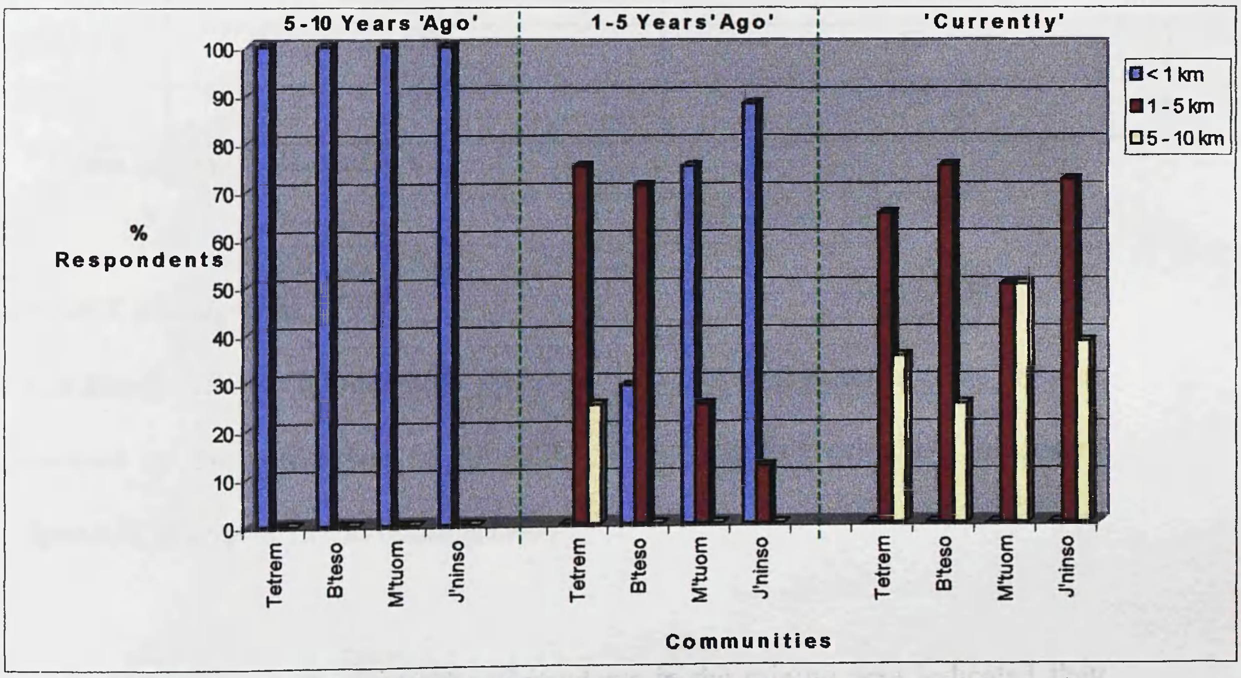

Figure 6.14: Distances Covered by Housewives in the BGM Mining Area to Fetch Fetch Firewood over time

When asked about what they perceived to be the reason(s) for the increasing distance to sources of firewood over the years (Table 6.9), all (100%) respondents at Tetrem, Bonteso and Mpatuom, and 90% of the Jeninso respondents were of the view that the problem could be attributed to mining-related devegetation. Some of the interviewees (Tetrem – 20%; Bonteso and Jeninso – 60%; Mpatuom – 50%) also believed farming-related devegetation could also be blamed for the increasing distances to firewood sources in their communities over the years.

Table 6.9: Perceived causes of Increasing Distances to Firewood Sources in the BGM Mining Area

	Perceived causes of Increasing Distances to Firewood Sources	
Communities	Devegetation (mining)	Devegetation (farming)
Tetrem	100	20
Bonteso	100	60
Mpatuom	100	50
Jeninso	90	60

* Values indicate % Respondents

iv. *BGL Mining Area*

Just like in the other mining areas, there had been a gradual increase in the distance covered by the housewives in the BGL mining area to reach their sources of firewood (Figure 6.15), as outlined below:

- 5 – 10 years 'ago', all (100%) respondents in the mining area indicated they walked less than 1 km from their respective communities to have access to adequate firewood for household cooking. None of the respondents travelled more than 1 km in search of firewood during this period (5 –10 years prior to the survey)

- 1 – 5 years 'ago' some of the respondents from Kumsono (25% of respondents) and Kwameniampa (43% of respondents) covered distances below 1 km to reach firewood sources. None of the respondents from Chujah and Odumasi covered distances less than 1 km to reach firewood sources for household use during this period. In fact, all (100%) respondents from these two communities reported that between 1 – 5 years 'ago' they had to cover an average distance of 1 – 5 km to obtain adequate firewood for domestic cooking. During the same period, 75% of the Kumsono respondents and 57% of the Kwameniampa respondents said they trekked between 1 – 5 km to reach their firewood sources

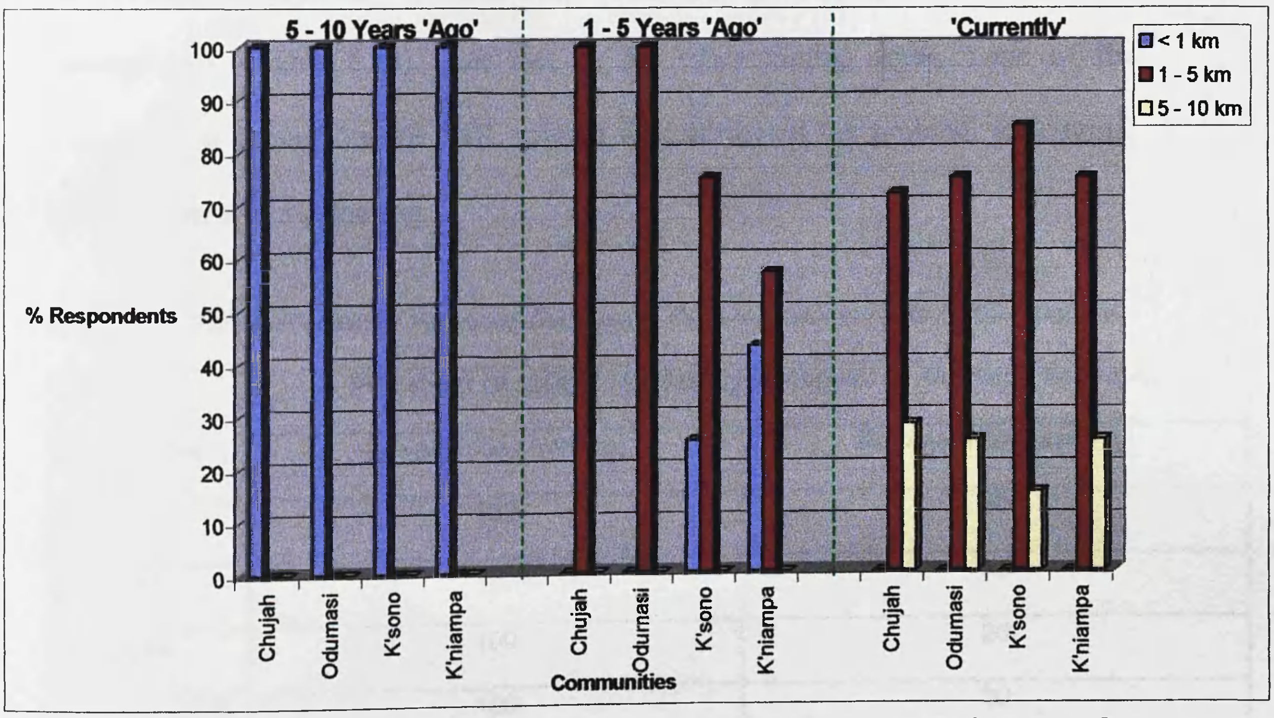

Figure 6.15: Distances covered by Housewives in the BGL Mining Area to Fetch Firewood over time

- During the survey period ('currently'), none of the housewives in the BGL mining area could obtain adequate firewood less than 1 km from their respective communities. Most of them (Chujah – 72%; Odumasi and Kwameniampa – 75%; Kumsono – 85%) said they trekked between 1 – 5 km to obtain adequate firewood for household cooking. During the same period, some of the housewives (Chujah – 28%; Odumasi and Kwameniampa – 25%; Kumsono – 15%) reported that they had to travel between 5 – 10 km to obtain their household firewood requirements

While all (100%) housewives interviewed in the BGL mining area thought devegetation through BGL's mining operations was the main cause of the difficulty in obtaining sufficient firewood locally, some of them (Chujah – 40%; Odumasi and Kwameniampa – 30%; Kumsono – 20%) also blamed it on farming-related devegetation (Table 6.10). Just like in the other mining areas, none of the interviewees throughout the BGL mining area attributed the problem to logging, bushfires or wood gathering.

Table 6.10: Perceived causes of Increasing Distances to Firewood Sources in the BGL Mining Area

	Perceived causes of Increasing Distances to Firewood Sources	
Communities	Devegetation (mining)	Devegetation (farming)
Chujah	100	40
Odumasi	100	30
Kumsono	100	20
Kwameniampa	100	30

* Values indicate % Respondents

6.5 Impact Mitigation Measures Preferred by the General Community in the Study Area

Table 6.11 shows the preferred mining impact mitigation measures, as indicated by the general community in the study area. Detailed below are the community-preferred impact mitigation measures.

i. *Reduction of Air, Water and Soil Pollution*

When asked to specify 5 environmental problems they would like the mining company operating close to them to prioritise for tackling, all (100%) respondents in each of the 16 communities in the study area included 'pollution reduction'. Community members in each of the study communities indicated they would like the company operating close to them to take adequate measures to reduce air, water and soil pollution in their community.

ii. *Payment of Compensation*

In each of the 16 communities, all (100%) respondents expressed dissatisfaction about compensation paid to community members who lost their property to mining activities and felt that in future, compensation issues should be given priority attention in the mining companies' bid to mitigate the adverse impacts of their surface mining operations. Although it was generally acknowledged compensations had been paid to community members in the past, the general feeling was that they were not commensurate with the losses resulting from the destruction of farms, farmlands and other property. Community members were particularly worried about the fact that no compensation was paid on farmlands that had not been cultivated at the time they were lost to mining activities.

Table 6.11: Impact Mitigation Measures Preferred by the General Community in the Study Area

Mining Areas	Communities	Community-Preferred Mining Impact Mitigation Measures					
		Pollution Reduction	Compensation	Health	Natural Resource Preservation	Rehabilitation	Potable Water
AGC Mining Area	Sansu	100	100	100	30	100	70
	Aduaneyede	100	100	100	35	100	65
	Ahansonyewodea	100	100	100	35	100	65
	Ampunyasi	100	100	100	40	100	60
RAL Mining Area	Manso-Nkran	100	100	100	35	100	65
	Koninase	100	100	95	30	100	70
	Dadease	100	100	85	30	100	70
	Kaniago	100	100	75	20	100	80
BGM Mining Area	Tetrem	100	100	100	25	100	75
	Bonteso	100	100	100	15	100	85
	Mpatuom	100	100	100	15	100	85
	Jeninso	100	100	75	40	100	60
BGL Mining Area	Chujah	100	100	100	30	100	70
	Odumasi	100	100	80	25	100	75
	Kumsono	100	100	100	15	100	85
	Kwameniampa	100	100	85	25	100	75

* Values indicate % Respondents

iii. *Provision of Clinics / Other Health Facilities*

The proportions of community members who wanted the above mining impact mitigation measure prioritised by the mining companies in the study area were as follows:

- In each of the four communities in the AGC mining area, all (100%) respondents listed 'provision of clinics / other health facilities' among the five most important things they would like AGC to do for their respective communities

- In the RAL mining area, most of the respondents from the general community (Manso-Nkran – 100%; Koninase – 95%; Dadease – 85%; Kaniago – 75%) said they wanted RAL to assist in the establishment of clinics or other health facilities in their respective communities
- In the BGM mining area, all (100%) respondents from Tetrem, Bonteso and Mpatuom, and 75% of the Jeninso respondents indicated they would like BGM to assist their communities to establish clinics or other health facilities
- In the BGL mining area, most of the respondents from the general community (Chujah and Kumsono – 100%; Odumasi – 80%; Kwameniampa – 85%) said they wanted BGL to assist in the provision of clinics or other health facilities in their communities

iv. *Preservation of Natural Resources*

In each of the 16 communities in the study area, less than half of the respondents (in fact, less than 40% of respondents in 14 of the 16 communities) listed 'preservation of natural resources' among the five top community-preferred mining impact mitigation measures. Most of the respondents who thought this was not an issue worth prioritising felt a considerable proportion of community natural resources had been destroyed already through mining activities, and that the preservation of what was left would be of no significant benefit to their community members.

v. *Rehabilitation of Land / Other Natural Resources*

In each of the 16 communities in the study area, all (100%) respondents indicated that they would like the mining company operating close to them to rehabilitate the communities' once forested / fertile lands and fish-rich, potable water bodies for use by community members after cessation of mining operations. While they would like to have their lands returned to them in a state suitable for crop cultivation, they would also like their rivers and streams treated, detoxified, etc., to make them drinkable and suitable for habitation by fish and other aquatic animals.

vi. *Provision of Potable Water*

In the AGC mining area, an average of 65% of respondents wanted AGC to prioritise provision of adequate potable water for communities in the mining area, in the company's mining impact alleviation measures. In the RAL mining area, an average of 71.2% of the respondents included 'provision of adequate potable water' in their list of 5 most-preferred mining impact mitigation measures they would like RAL to embark upon. Most of the respondents in the BGM mining area (Tetrem – 75%; Bonteso and Mpatuom – 85%; Jeninso – 60%) indicated that provision of potable water was one of five most important things BGM should consider prioritising in the company's mining impact mitigation measures. In each of the four communities in the BGL mining area, majority of the respondents (Chujah – 70%; Odumasi and Kwameniampa – 75%; Kumsono – 85%) said provision of adequate potable water for their communities was one of the most important issues they wanted BGL to address in their communities

CHAPTER SEVEN

DISCUSSION

7.1 Introduction

From the results of the field study reported in chapters five and six, it is clear that many mining-related environmental and socio-economic concerns were raised by communities in the study area. However, efforts are being made by the mining companies operating in the area to address these concerns. Steps are being taken by the companies to enhance the positive impacts of their operations. Measures are also being taken to mitigate the adverse impacts associated with the various phases of their mining operations. Given that there are still large deposits of near-surface gold ore in southern Ghana, the exploitation of which will last several decades (Addy, 1998), the onus is on the mining companies operating in the region to improve mitigation of the adverse impacts of their operations. At present, the effectiveness of the measures pursued at most of the mines leaves much to be desired. In section 7.2, the environmental performance of the four studied mines is compared. It is worth stating that while poor and / or ineffective environmental management can be blamed for most of the environmental and socio-economic impacts of mining, some of the problems are due to, or are exacerbated by, the inherent properties of the ore being exploited. The environmental setting of the mining area and its surroundings also plays a significant role as far as the types and levels of adverse impact created at a mine are concerned (Kuyucak, 1998). Therefore approaches to effective mitigation of adverse mining impacts should entail not only the design and implementation of appropriate environmental management practices, but also, an in-depth understanding of the mining area environment. In section 7.3, this issue is discussed in relation to southern Ghana. In section 7.4, the causes of the adverse impacts of surface gold mining in southern Ghana are briefly discussed together with the current approaches to minimising these impacts by the mining companies operating in the region. Also discussed in this section is the need for the use of a clearly defined Environmental Management System – which should encompass all the environmental management programmes and strategies of the company, together with a clear management control and policy structure – for the companies' operations to operate to.

The development of Environmental Management System (EMS) based on the ISO 14001 EMS standard is proposed and discussed in section 7.4.1. Since Ghana (through the Ghana Standards Board – GSB) has already registered with the ISO, it is envisaged that in future, most companies in the country seeking international certification of their EMS will adopt the ISO-14001 EMS standard. In Australia for instance, Standards Australia has adopted the ISO 14000 series (Brooks *et al*, 1996). The ISO 14001 EMS standard is described in detail towards the end of section 7.4.1. In section 7.5, steps for the development of an ISO 14001-based EMS and for the attainment of environmentally sustainable and socially responsible gold mining in southern Ghana are proposed and discussed. Considerations such as the mining area community's concerns and preferred mining impact mitigation measures are particularly expounded in this section. Recommendations for improvement in environmental management in future mining operations in southern Ghana are presented in section 7.6, which concludes this chapter.

7.2 Environmental Performance of the Mining Companies in the Study Area

The measurement of environmental performance of companies is concerned with the identification, assessment and evaluation of the environmental effects of the companies' operations, with the aim of: (i) gaining a better understanding of what these effects entail; (ii) improving the management of such effects; and (iii) reducing the effects of the system under scrutiny (Wehrmeyer and Tyteca, 1998).

Various authors (including Repetto, 1992; Hocking & Power, 1993; Peacock, 1993; Eden, 1994; De Green, 1994; Tyteca, 1996; Wehrmeyer & Tyteca, 1998) have reported on the difficulty of measuring the environmental performance of industries. According to Repetto (1992), this difficulty is partly attributable to the fact that mainstream economic philosophy and modelling assign no economic value to depletion of resources like water supplies, soils, forests, fisheries and wildlife, nor to reductions in biodiversity, destruction of irreplaceable ecosystems and perturbation of world climate. Hocking and Power (1993) have attributed the problem to the fact that over the years, there have been no attempts to standardise environmental performance indicators, which would allow comparison of environmental performance among firms and over time. As identified by Peacock (1993), while companies can reduce environmental measurement costs by exploiting situations where government regulations require quantitative information for the evaluation of their environmental performance, some important parameters (such as the local community's perception of a plant) are extremely difficult to quantify. Wehrmeyer and Tyteca (1998) have attributed the problem to the following factors among others:

- Not enough standardisation between performance indicators
- Lack of integration of such measures into the wider context in which they should be seen – in this, environmental performance assessment remains, as yet, a highly disjointed exercise
- Efforts to quantify *outputs* (environmental effects) cloud the need for information on environmental *impacts* (results of outputs). In other words, rather than measuring the ecological impact of outputs, firms too often measure the volume and legal quality of such outputs
- Despite a small but growing number of useful approaches, the efforts to combine performance measures across environmental media remain largely unsatisfactory. For example, the essential question of *how much pollution of x of the water equates to 1 unit of pollution of y in the air?* remains the subject of speculation that often reveals the values of the authors more than they resemble ecological reality
- Very few studies analyse environmental effects over time

Due to the problems above, 'relative' indicators are often used to assess environmental performance of firms. In this respect, a 'relative quantity' is defined as the result of the comparison of a given absolute variable with some predefined level, such as worst or best practice, or some standard coming from legislation, or any specified target (Tyteca, 1996). Another commonly used ('relative') environmental performance indicator is the 'percentage of control samples that complied with a given quality standard for a given period' (Haines, 1993). These two approaches to assessing environmental performance (Tyteca, 1996; Haines, 1993) are employed in the assessment of the environmental performance of the four mining companies in the study area. While results from environmental monitoring data collected by the mining companies are compared with 'maximum permissible limits' set by the Ghana Environmental Protection Agency, the environmental performances of the companies are evaluated against 'Best Practice Environmental Management in Mining [BPEM] (Environment Australia, various years: see Sections 2.5.3.1 – 2.5.3.12 [Chapter 2] and Appendices 2 – 13).

The 'BPEM in Mining' set of publications comprises modules on various aspects of environmental management in mining, including the aspects shown in Table 7.1. The modules are aimed at illustrating current best practice by the mining industry within Australia, and to encourage others to strive for a similar level of performance (Brooks *et al.*, 1996). The BPEM modules are the outcome of a decision taken during a meeting of the International Association of Impact Assessment (IAIA) held in Ottawa in 1994. During the meeting, which was attended by representatives from the World Bank, the United Nations Environment Programme (UNEP) and other international agencies, Australia was asked to take the lead in showcasing examples of best environmental practice in all aspects of the mining industry (Environment Australia, 1995h). A partnership between the Australian Government's Environment Agency and the Australian mining industry was subsequently formed in response to this request. This partnership has resulted in the publication of a video and a number of modules in the form of booklets, which demonstrate the best practice of the leading environmental managers in the mining industry in Australia. The modules aim to (Environment Australia, 1995h):

- Demonstrate examples of best practice environmental management in the Australian mining industry
- Promote this experience and expertise in environmental planning, impact assessment and management
- Assist the resource sector overseas by making this expertise available internationally

One good characteristic of the modules is that they address both domestic and international needs (Environment Australia, 1995h). The performances of the four mining companies as regards the effectiveness of their adverse impact mitigation measures [as measured against BPEM (Appendices 2 – 13)] are discussed in the sections below.

Table 7.1 shows the environmental performance of the four mining companies selected for this study.

7.2.1 *Mine Planning for Environmental Protection*

As shown in Table 7.1, with the exception of RAL which had incorporated effective planning into the pre-mining, constructional and operational phases of its mining operations, the planning of mining activities to maximise environmental

Table 7.1: Environmental Performance of the four Mining Companies in the Study Area

MITIGATION MEASURES TO REDUCE MINING IMPACTS	RAL	BGL	BGM	AGC
Mine Planning for Environmental Protection	F	P	P	P
Community Consultation & Involvement	P	N	P	N
Environmental Impact Assessment	F	na	na	F
Environmental Management System (s)	N	N	N	N
Exploration	F	P	N	P
Dust Control	F	F	P	N
Water Management	F	F	P	P
Noise, Vibration & Blast Control	F	P	P / na	P
Cyanide Management	F	N	na	P
Tailings Containment	F	F	P	P
Management of Sulphidic Mine Waste & Acid Drainage	F	P	na	P
Environmental Monitoring & Performance	P	P	P	P
Rehabilitation & Revegetation	F	F	F	P
SCORES AGAINST ARBITRARY MAXIMUM OF 2 = BPEM	1.69	1.17	0.9	0.85

INDICES (With Respect to BPEM)

* F= full compliance (score=2); P= partial compliance (score= 1); N= none or little compliance (score= 0)

protection had only been 'partially' undertaken by the mining companies in the study area. Prior to RAL commencing gold mining operations in the Manso-Nkran area, representative samples of air and water were taken over a period of more than a year as part of their baseline air and water quality studies in the area. Comprehensive AMD study / characterisation was also carried out prior to the commencement of active mining. Mine site facilities were located as far away as possible from community residential areas. Again, dense vegetation was left intact at the periphery of its concession to act as a buffer zone, screening community / community property from the mine / mine site facilities. In contrast, the baseline studies on ambient air and water quality undertaken by AGC prior to the commencement of its Ashanti Mine Expansion Project (AMEP) was carried out over a 10-day period in one month (June 1998). This study was too short and limited to be representative of an environment with wide variations in climatic conditions across the year. During the pre-mining phase of the AMEP, no study on AMD generation potential of the ore body of AGC's AMEP site was undertaken. This was a serious planning error, given the fact that gold mineralisation in the mining area is accompanied by the formation of pyrites and arsenopyrites (see section 4.2.2 (i) of Chapter 4) – the most important ingredients for AMD formation. It is worth noting that early characterisation and modelling of AMD generation characteristics prior to the operational stage of mineral development are essential for effective AMD control during the operational phase of mining (Orava & Swider, 1996). Another planning issue of concern at AGC's surface mine site is screening. Unlike RAL, no vegetation has been left around AGC's Sansu mine to act as a buffer (screen) between the mine and the mining area communities and their property.

In the case of BGM, just like RAL, the company (BGM) has left forested areas at the edges of its Tetrem concession to provide some screening from the surrounding community. However, several issues on planning for environmental protection were not adequately pursued by BGM prior to active mining. For instance, prior to the commencement of its alluvial gold mining operations in the Tetrem area, the baseline studies carried out were limited to few features of the mine site and surroundings. The main features studied were the status of water resources, soil resources, flora and fauna, and, historical and archaeological resources. No study on ambient air quality was undertaken. Again, no estimate of water balance / budget was conducted by BGM prior to the commencement of active mining, despite the importance of a knowledge of water balance / budget to effective environmental management of floodplain mining operations [especially, for effective management of tailings / tailings dams (Environment Australia, 1995d)]. Another mine planning issue of concern at BGM is the location of some mine site facilities too close to community residential areas. A typical example is the ore processing plant, located less than 50 m from a residential unit at Tetrem.

Like BGM, prior to the commencement of mining operations, BGL undertook baseline studies just enough to cover key environmental features of its mine site near Bogoso. Studies on AMD generation potential at the BGL mine were carried out at some stage during the operational phase of mining after AMD-related problems had started to surface at the mine. Ideally, studies on AMD generation potential of the mining area bedrock should have been carried out prior to the commencement of mining operations. Some mine site facilities at BGL were found to be too close to residential areas of the mining area community. At Chujah for instance, a waste dump had been sited less than 40 m from a residential building.

7.2.2 ***Community Consultation and Involvement***

Community consultation and involvement in the various phases of mining can be said to have been only 'partially' undertaken by RAL and BGM, and 'poorly' undertaken by AGC and BGL. Community consultation and involvement in respect of food production and access to potable water are emphasised in this section. Although all four mining companies held discussions with community leaders prior to commencing mining operations in their respective mining concessions, this was one of the legal requirements that the companies had to fulfil before being issued with an operating permit to start mining. In places (like Ghana) where EIA is required by law, one of its tasks is to ensure that enough information is available to all concerned parties for them to be able to make informed decisions. Affected local communities and other stakeholders need to know what impact the planned activity would have on their quality of life and their societal well-being. This means relevant information has to be freely made available to them in a language and format easily understood – 'user-friendly' information that is not misleading, cannot be misunderstood or easily misinterpreted (Kakonge, 1998). However, in the pre-mining community consultation process, community members in the study area were kept in the dark about the effects mining activities were going to have on the quality of water bodies in the area. This is evidenced in their expression of 'surprise' about pollution of their natural water sources which had adversely affected aquatic life and the use of stream / river water for domestic and other purposes.

Throughout the study area, community members expressed disappointment about low compensation paid to them following destruction of farms and other property as a result of mining activities. Again the non-payment of compensation on land without crops at the time the land is lost to mining activities is a decision the local communities are in total disagreement with. The stance of the mining companies is clear and understandable: the Land Valuation Board of Ghana (LVBG) determines the compensation rates for various types of crops and property, and firms are only obliged to pay compensation not less than the rates set by the LVBG for damage to land, land use and structure (Domfe, 2003). Again, the non-payment of compensation on uncultivated land is a government policy that the companies adhere to, and for which the companies can not be blamed. This issue, if not properly addressed, will promote large scale 'speculative' farming in the region, which may lead to reduced soil fertility and land degradation as farmers are compelled to break away from the traditional shifting cultivation and bush fallow systems of farming commonly practised in southern Ghana (which enhance soil rejuvenation). It must also be pointed out that a careful study of the situation by the companies may have led to the striking of a compromise deal with the communities, as was done by Seafor Mining Company (Ghana) Limited (SMCL) in 1998. Following a study in the Mpeasem area (Central Region of Ghana) by Mireku-Gyimah (1997) that found that the compensation rates for cash and food crops established by the Land Valuation Board of Ghana (LVBG) were woefully low, SMCL adjusted the rates upwards. This was done prior to the commencement of SMCL's Mpeasem gold mining project in 1998 to the satisfaction of communities in the Mpeasem area (Mireku-Gyimah, personal communication). In Mireku-Gyima's (1997) study, it was ascertained that the value of LVBG's rates (last established in 1982) had eroded significantly due to inflation. To offer reasonable compensation acceptable to the mining area community, SMCL computed the dollar equivalent of LVBG's compensation rate for each type of crop as at 1982. This rate (in dollars) was then used in compensating community members who lost farms / other property to the Mpeasem gold mining project. It is important that mine management provides appropriate compensatory packages and support to impacted communities. Although no single economic and benefit package is capable of compensating for lost land entirely, management must nevertheless commit time and resources to improving socio-economic quality of life in communities by tailoring compensation to address local needs (Hilson, 2002b). Hilson (2002b) has recommended that community compensatory programmes in mining areas feature, at minimum, the following:

- A fully-researched reporting providing details (issued to community groups) of the company's compensation procedures and policies, relevant stakeholder parties and, if applicable, details of community relocation
- Direct compensation to individuals for any natural resources (including trees, soils and water) and economic resources (such as crops) potentially impacted by mining activities
- Provision for housing, wells, medical facilities and road infrastructure, in the event of relocation
- Direct funding for re-skilling and employment programmes for residents
- Issuance of a mandate to hire locally, and a commitment to training

The current situation in the study area where local communities are not party to negotiations on compensatory packages and the non-payment of compensation on land not cropped at the time of land valuation for the determination of compensation packages, has to change. Ghana can learn valuable lessons on compensation from Fiji. At some stage in Fiji's history, friction between landowners in mining areas on the one hand, and explorers and developers on the other, was very common due to the former feeling that fair compensation was not being paid (by proponents) for land acquired for mineral development or following destruction of property (McLeod, 2000). To resolve the problem, a compensation policy entitled 'Compensation Policy for Fiji's Mineral Sector' was developed following several months of intense discussion and research by the 'Compensation

Committee', a multidisciplinary team from various government departments in Fiji (McLeod, 2000). An aspect of Fiji's approach to the development of this policy worth considering for possible adoption or adaptation by Ghana is its extensive stakeholder review with landowners, the private sector, non-governmental organisations (NGOs), the indigenous Fijian chiefs and the general public (McLeod, 2000). One important aspect of the Fijian compensation system is the way compensation is calculated and paid to affected landowners. Cognisance is taken of the following values of land among others, in deciding on compensation packages for landowners: direct use value; indirect use value; option value; and bequest value, which are explained briefly below (McLeod, 2000):

i. *Direct Use Value*

This refers to the value accrued from the direct use of the land such as through crops, timber, non-timber forest products, pasture, recreation and medicinal plants

ii. *Indirect Use Value*

These are values derived indirectly from the land use including watershed protection from floods and protection from soil erosion

iii. *Option Value*

This refers to the premium placed on the option of keeping the land available for future use

iv. *Bequest Value*

This value reflects the importance placed on transferring land to future generations

According to McLeod (2000), the 'bequest value' of land is particularly important, as land is a birthright in the Fijian culture and is passed on to children. If the land is irreversibly changed, there is a loss to the current generation of not being able to pass it on to future generations. Land ownership in Ghana is similar to what obtains in Fiji, but the method for compensating farmers and other people affected by mining activities in Ghana (which has been explained previously) is currently different from the method used in Fiji. The system of taking the 'option' and 'bequest' values of land into account when compensating landowners in mining areas in Fiji, if introduced in Ghana, would be a great relief to landowners in potential mining areas in the country.

As regards responding to community concerns during the operational phase of mining, only RAL and BGM can be said to have demonstrated some level of 'best practice'. RAL, having identified provision of adequate potable water as a key issue to be addressed in the Manso-Nkran area, had taken steps to address the issue, to the satisfaction of communities in the area. The company had also paid heed to farmers' plea for support, by establishing a 'sustainable livelihood project' (SLP) [described in detail in section 5.3.2 (v) of Chapter 5], which had led to substantial improvement in the socio-economic lives of farmers in the Manso-Nkran area. An important issue that the company had failed to address at the time of the field survey was the community complaint that they had been denied access to the unmined forest at the periphery of the company's concession. This denial, according to the communities, had compelled them to trek long distances in search of mushrooms, roofing materials and firewood which, prior to RAL commencing mining activities in the Manso-Nkran area, could be obtained within easy access for free. The communities' worry may be put down to their lack of adequate understanding of the 'screening' role of the forest in question. It might be necessary for RAL to set up an Environmental Education Committee within its Environmental Management Department or Public Relations Department to educate the communities in its mining area on this and other issues with a bearing on the mining area community.

A remarkable move to address community concerns in the BGM mining area is BGM's progressive rehabilitation programme that has led to 75% of mined out areas having been backfilled and recontoured, with 11% of mined-out areas already revegetated as at the time of the survey. This concurrent reclamation programme is to ensure that farmers in the various communities surrounding the mine could be given back their land in a form suitable for them to be able to commence farming activities soon after cessation of mining operations. Community concerns requiring urgent attention in the BGM mining area include the provision of adequate potable water for the communities that have expressed dissatisfaction with the quantity of potable water that BGM has supplied.

Most communities in the AGC mining area are worried that AGC has not taken adequate steps to respond to their complaint about the quality and quantity of potable water available to them, after the destruction of their natural water sources through AGC's mining operations. One community in the BGL mining area also referred to a similar experience with BGL. In the AGC mining area, farmers' complaints about the destruction of their crops by waste water from AGC's ore processing area containing cyanide residue (referred to as 'semet' locally) had yet to be addressed. Similarly, community members in the BGL mining area were worried about BGL's failure to embark on measures to halt the destruction of their buildings through mining activities.

It must be stated that local communities can contribute positively to environmentally sustainable mining when given the necessary guidance, training and incentive. This argument is supported by Appiah-Opoku (2001), who has suggested that indigenous ecological knowledge could be used to supplement the scanty scientific data and information in Ghana during EIA studies. Hilson and Murck (2000) give a comprehensive account of how an international mining company – Placer Dome Inc – has forged a fruitful partnership with local communities at its gold mine in Niger (West Africa). At its exploration sites of this mine, Placer Dome Inc – Canada's second largest gold miner – has developed a partnership with the World Conservation Union in examining the issue of site rehabilitation through co-operative action with the local community (Hilson & Murck, 2000).

7.2.3 *Environmental Impact Assessment*

Before 1 January 1995, it was not a mandatory (statutory) requirement for mining companies in Ghana to undertake EIA studies before being granted the necessary permits / licences to commence mining operations. However, between 1974 and December 1994, mining companies were obliged to submit to the Minerals Commission and the EPA, an Environmental Action Plan covering the status (including environmental conditions) of their concession, their mineral development plan, potential impacts of their proposed operations, and an impact mitigation plan. None of AGC's mining operations that took place in the Obuasi area between 1897 and December 1994 were preceded by EIA. Similarly, BGM and BGL, whose mining operations in the study area commenced in 1991 and 1990 respectively, did not voluntarily undertake EIA studies on their mineral development projects prior to the commencement of active mining in their respective concessions. With the coming into force of the Environmental Protection Agency Act 1994 (Act 490), beginning from 1 January 1995, section 12 (1) of the Act made it mandatory for all large scale mining operations > 10 ha to be preceded by EIA. Therefore, prior to the commencement of AGC's Ashanti Mine Expansion Project (AMEP) in late 1999, and RAL's Tetrem gold mining project in 1996, the two companies undertook EIA studies of their concessions and environs. After a review of the Environmental Impact Statements (EISs) supporting the EIA studies by EPA (Ghana), environmental permits were granted for AGC (in 1999) and RAL (in 1996) to commence mining activities in their respective concessions. Although details of the EIA studies are not presented in this thesis, the fact that EPA eventually gave AGC and RAL environmental permits to commence active mining gives an indication that EPA was satisfied with the quality of the assessments. It also suggests that the studies covered all areas stipulated by EPA in its 'Ghana Environmental Impact Assessment Guidelines', a document that guides project proponents on environmental impact assessment studies and the preparation of environmental impact statements. This, notwithstanding, a few problems can be identified with the assessment of the EIAs by EPA. For instance, although AGC failed to collect representative samples during its baseline studies for the AMEP, it obtained an environmental permit to commence the project in 1999. Again, it can be concluded from the responses of communities in the RAL and AGC mining areas (where EIA had been previously carried out) that there was little public participation in the EIA process. Public participation is conceived as a significant stage that influences the overall EIA process (Purnama, 2003). For instance, in mine water management, awareness of the level of community concern regarding pollution, and involvement of community groups in remediation programmes, brings with it a range of benefits, some of which are listed below (Jarvis and Younger, 2000):

- Local knowledge can provide an invaluable insight into the origins of mine water pollution and its historical nature and severity
- Correctly instructed, local community members may assist with sample collection and EIA studies
- Local communities can assist with construction of remediation schemes, and perhaps more significantly, can ensure day-to-day maintenance of such facilities

In EIA studies, it must be borne in mind that expert opinion does not necessarily imply scientific knowledge. Indigenous people who are regarded by local people as 'experts' in the areas of interest could be co-opted to help in the assessment and prediction of impacts of a proposed project (Appiah-Opoku, 2001). By promoting participation processes, communication among EIA stakeholders can be enhanced, with opportunities for interaction and mutual clarification (Purnama, 2003). Conditions that make people anxious and suspicious, especially from directly affected communities, can be minimised or at least suitably managed through public participation. At the same time, communities may obtain useful information to help them prepare necessary plans and actions needed to overcome the impact of proposed activities (Purnama, 2003). Even where there is public resistance, it should be viewed as a challenge to be resolved in order to fulfil one's investment needs. Obtaining feedback from the public to improve a project proposal is important in the sense that if public involvement is adequately addressed eventually, the proponent can build trust and establish a positive partnership, which can be used as a means of empowering the public (Purnama, 2003).

Despite the limitation associated with EIA studies in Ghana, it must be pointed out that the introduction of the EPA Act 1994 (Act 490) has led to some improvement in environmental management in the mining sector. This is evidenced in the remarkable environmental performance of RAL, the only mining company in the study area whose entire operations commenced after the promulgation of the Act (see Table 7.1). Following EPA's directive that all large scale mining companies in Ghana monitor the environmental quality of water bodies in their mining area (a condition for continuation of mining operations enshrined in the EPA Act 1994 (Act 490), mining companies in southern Ghana are making tremendous efforts to minimise pollution of water bodies at their mines. This can be seen in the environmental management and monitoring programmes put in place at the various mines in the study area (Chapter 5) and is also evidenced in the water quality monitoring results of some of the mines in the study area (specifically, RAL and BGL) – as shown in Appendices 15 and 16. For instance RAL exceeded the Ghana EPA's maximum permissible limit (EPAMPL) for various pollutants on very few occasions (in fact, only 4 occasions) in a two-year period (see Appendix 15). BGM, on the other hand, performed badly only in the minimisation of Total Dissolved Solids, in which case the EPAMPL was exceeded on all occasions throughout the two-year monitoring period (see Appendix 16).

It is hoped that in future, while the mining companies in Ghana make efforts to undertake their EIA studies in line with the requirements of Ghana EPA, they also endeavour to use 'best practice' approaches (such as the approaches outlined above and those recommended by Environment Australia [1995c]) during the studies.

7.2.4 *Environmental Management System(s)*

None of the mining companies in the study area had an Environmental Management System (EMS) in place despite its importance to the effective management of adverse mining impacts and to the enhancement of positive mining impacts. Table 7.2 summarises the components of an ISO 14001 EMS standard. In fact, the use of an appropriate EMS would help avoid or at least minimise most of the adverse impacts created at the various mines in the study area, as explained in sections 7.3 – 7.6.

7.2.5 *Exploration*

All four mining companies had undertaken exploration activities several years before the field study. To this end, in ascertaining their performance in respect of their exploration activities, the state of the sites where exploration activities had

Table 7.2: The Phases / Elements of an ISO 14001-based EMS (After Martin, 1998).

PHASE OF EMS	ELEMENTS
1. **Policy**	Environmental Policy
2. **Planning**	Environmental Aspects
	Legal & Other Requirements
	Objectives & Targets
	Environmental Management Programme (s)
3. **Implementation & Operation**	Structure and Responsibility
	Training, Awareness & Competence
	Communication
	EMS documentation
	Document Control
	Operational Control
	Emergency preparedness and Response
4. **Checking & Corrective Action**	Monitoring & Measurement
	Non-conformance & Corrective & Preventive Action
	Records
	EMS Audit
5. **Management Review**	Environmental Management Review

been carried out in the past (especially, signs of 'inappropriate' exploration activities) was assessed.

It was only at the RAL mine site that the application of 'best practice' in mineral exploration activities was evident. None of the community members interviewed in the RAL mining area mentioned any identified environmental problems related to RAL's exploration activities in the Manso-Nkran area. Again, there were no visible signs showing impacts of past exploration activities (such as uncovered trenches and bare / eroded exploration sites) during the site visit. In fact, from the discussions held with the communities in the RAL mining area, the assertion made by RAL in their completed questionnaire that indicates that they carried out their exploration activities in line with 'best practice' (see Appendix 5) could not be doubted. In the AGC and BGL mining areas, steps to mitigate the adverse impacts of their exploration activities had only been 'partially' undertaken. Although there was evidence of backfilling of exploration trenches and rehabilitation of the filled trenches at several exploration sites that were visited in the two mining areas, at some of the exploration sites, exploration trenches had neither been backfilled nor revegetated. The excavated soil at the edges of the trenches is washed into water bodies in the two mining areas, causing siltation and pollution problems, while the open trenches remain 'death traps' to wild animals. For instance, at Ampunyasi (AGC mining area), community members indicated that a perennial stream (Aponapono) – the main source of potable water for the entire Ampunyasi community – turns turbid during the rainy season as a result of loose soil left at the edges of exploration trenches on a hill adjacent to the stream, that gets washed into the stream. This, according to the Ampunyasi respondents, compels them to use the AGC-provided bore-hole water which they do not consider potable enough for consumption.

It could be inferred from the state of BGM's exploration sites that as far as minimisation of environmental impacts is concerned, exploration activities were 'poorly' carried out by the company. A common feature at BGM's mine site is open exploration trenches. According to the communities in the area, these trenches get filled with water during the rains, and become breeding grounds for mosquitoes.

7.2.6 *Dust Control*

Adequate steps were being taken to control dust pollution in the RAL and BGL mining areas. On the contrary, dust control measures were only being 'partially' pursued by BGM and AGC. In the RAL mining area, effective dust control measures were in place, including the use of mobile bowsers on roads used by mine vehicles and limiting of speeds of mine vehicles to limits that ensure minimal generation of dust during the dry season. Blasting is also scheduled as much as possible to coincide with favourable weather conditions, in addition to watering of the blast area prior to blasting, to minimise dust pollution. In addition to this, waste dumps are regraded and reshaped in sections and sequential revegetation carried out to stabilise them, reducing the incidence of blown dust usually associated with waste dumps, especially during the dry season. Another important dust pollution control measure pursued by RAL is the extraction of dust from the processing plant's comminution circuit using High Energy Venturi Scrubbers and a Baghouse (synthetic fabric filter system). There were no visible signs of dust pollution from roads or the mine site throughout the field study period, which was carried out in the dry season. In the same way, dust was being effectively controlled at the BGL mine. Most roads in the mining area (especially those used by mine vehicles) had been tarred through a collaborative effort between BGL and the Wassa West District Assembly. There were no visible signs of dust pollution even at the peak of the dry season (February) when the field survey was commenced. In fact, the field observations seemed to confirm what the two companies indicated in their completed questionnaire – that dust levels in all communities that had been monitored in the past were well below the Ghana EPA maximum permissible limit.

Although a number of air pollution measures were said to have been put in place by AGC and BGM, dust from the roads used by the companies' vehicles was a cause for concern. In the AGC mining area in particular, excessive dust generated by mine trucks was observed on several occasions in the Obuasi township, and in the four villages selected for the community surveys in the Obuasi area. The proximity of the mines to rural communities makes it necessary for the two mining companies to take adequate steps to control dust in the region. Dust pollution over a prolonged period may lead to formal complaints by the mining area communities and eventual legal action against the companies, as happened in the case of the Avoca Mines in South-East Ireland (Herr *et al.*, 1996).

7.2.7 *Water Management*

It was only at the RAL and BGL mines that adequate provision had been made for effective water management. At the RAL mine, a dense network of drains are strategically located to collect all mine site runoff for conveyance to the mine tailings dam. Most of the water in the dam is eventually recycled for reuse in the ore treatment plant. The tailings dam has incorporated in it, a fixed decant system for diverting excess water from the dam into a wetland filter system created downstream of the main (tailings) dam embankment. Again, the mine pit is equipped with a pumping system capable of removing all water in the pit within 24 hours of flooding, and discharging it into the tailings dam. An interesting waste / runoff water management strategy at RAL is the use of a recycling technique involving the pumping of decant water in the tailings dam via a pontoon-mounted pump system and a return water pipeline for reuse in the ore processing plant. This efficient water recycling system makes it possible to reuse otherwise excess water for ore procesing. That adequate measures are in place at RAL's Manso-Nkran mine to minimise water pollution is evident in the water quality monitoring results for monthly samples taken at the company's water effluent discharge point over a two-year period (Appendix 15). The Ghana EPA maximum permissible limit (EPAMPL) was exceeded only on four occasions (Total Cyanide – 1 occasion; Total Suspended Solids – 3 occasions). On no occasion did pH, Free Cyanide and Total Arsenic levels, and, Conductivity rates exceed the Ghana EPA maximum permissible limit throughout the two-year monitoring period.

At the BGL mine, a number of diversion drains (enough for the area covered by mining operations) have been constructed to channel runoff water to the mine tailings dam. Excess water in the tailings dam is either pumped to the ore processing plant for reuse or lime-treated prior to discharge to natural water courses, ensuring that the water quality of the discharged water is in compliance with Ghana EPA water quality guidelines. Use is also made of drainage and settling ponds to settle out suspended solids in runoff water. Again, surplus supernatant water from the surface of BGL's tailings dam is only discharged into a lake (Lake Marwood) after chemical analysis to ensure the lake water will not be polluted. Unfortunately, monitoring data to confirm BGM's 'claim' that the quality of the water discharged into the lake is in line with Ghana EPA water quality guidelines was not made available for examination for this study.

Management of waste / runoff water to minimise the adverse impacts associated with it was only being 'partially' undertaken by AGC and BGM. At both AGC and BGM, use is made of intercepting ditches to collect and channel runoff water to tailings dams, and of settling ponds, to allow suspended solids to settle. At both mines, waste water recycling / reuse mechanisms are in place, reducing the amount of excess water discharged into the environment. However, there are a number of problems with the management of waste / runoff water at both mines. For instance, at AGC, although a network of drains are in place to convey runoff water to the mine tailings dam, the number of drains is not adequate for effective runoff water management, given the size of the concession and the number of steep hills in the lease area. The discharge of household water (from the AGC housing units in the Pompora Treatment Plant [PTP] area) directly into the Kwabrafo River without treatment, is another water management issue AGC needs to address as a matter of exigency. AGC's water quality monitoring results over a two year period (January 1998 to December 1999) [Appendix 14] point to the need for the company to take pragmatic measures to improve upon its water management strategies. Key issues of concern emanating from the two-year water quality monitoring data include the following:

- With the exception of one month (August 1998), cyanide concentrations of more than half of samples analysed each month exceeded the Ghana EPA maximum permissible limit (EPAMPL)
- 227 out of the 287 samples analysed (79% of samples) had cyanide concentrations above the EPAMPL
- Fifty-four percent of samples collected from the River Nyam had cyanide concentrations above the EPAMPL
- Even at the peak of the rains (June / July), cyanide concentrations of most samples analysed (including samples from Rivers Kwabrafo and Nyam) exceeded the EPAMPL
- With the exception of three months (July, 1998, June 1999 and July 1999), for each month, more than 50% of samples analysed had arsenic concentrations exceeding the EPAMPL, with concentrations as high as 60 times the EPAMPL measured in the Pompora Decant water in February 1998
- In the Kwabrafo River, as much as 84% of water samples analysed had arsenic concentrations exceeding the EPAMPL, with very high concentrations in the dry months (e.g., nearly 16 times the EPAMPL in November 1998)
- On 6 occasions, water samples from River Nyam had lead concentrations two to three times above the EPAMPL
- All samples analysed had conductivity rates exceeding the EPAMPL, with as much as 92% of the samples having conductivity more than twice the EPAMPL

It may be argued that environmentalists should only be worried about the poor water quality of, and contamination of sediments in, the two monitored rivers (Rivers Kwabrafo and Nyam), since the water quality of the other 'holdings' monitored (tailings dams, coffer dams, settling ponds and sumps) do not directly affect plant and animal life. However, the fact that flooding is a common phenomenon in the study area means the holdings may overflow their banks and end up in the surrounding environment during the rains. It may also be argued that even if such 'overflows' occur, 'dilution' resulting from the floodwaters would reduce the concentration of pollutants carried in the floodwaters. It must however be stated that given the extremely high pollutant concentrations in some of the 'holdings', the concentration of the pollutants may not necessarily be reduced to the EPAMPL through dilution. It therefore goes without saying that the best way to avoid any possible environmental hazards related to water pollution is for AGC to take steps to improve upon its water management strategies along the lines of 'best practice'. It will be useful for AGC to consider adopting preventative strategies to help minimise toxic effluents from its mining operations, instead of using remedial measures towards the end of its operations in the Obuasi area. A major drawback with conventional end-of-pipe water pollution remedies is their inability to minimise ecological 'costs', since each works to treat pollution problems after they have occurred, rather than targeting them beforehand. The resulting ecological problems are often irreparable, therefore creating huge burdens for the firm (Hilson, 2000).

The main water management problem at BGM is the presence of several uncovered exploration holes that, according to communities in the Tetrem area, create an unsightly scene of pockets of dirty stagnant water during the rains. Apart from the unsightly scenes, the stagnant waters are potential breeding grounds for mosquitoes. Given that the mine is close to rural communities, the health implications of the standing waters (especially, the spread of malaria) can be disastrous. BGM may have to consider implementing a 'standing water' policy like RAL's. RAL has a policy of ensuring that standing water does not remain more than 7 days, to reduce the incidence of mosquito breeding / malaria in its mining area. Data from a two-year water quality monitoring programme using boreholes at four sites in the BGM mining area and a section of the Ofin River (Appendix 16) show that the concentration of total dissolved solids exceeded the EPAMPL at all monitoring sites. The EPAMPL was exceeded three times in 72% of the samples analysed over the two-year period. This calls into question, the efficiency of BGM's interception ditches and settling ponds intended for the reduction of total dissolved and suspended solids in water bodies in its mining area.

7.2.8 ***Noise, Vibration and Blast Control***

Only RAL had put in place all necessary measures to bring blasting-related noise and vibration under control. Steps to control blasts, noise and vibrations were only being 'partially' undertaken at AGC and BGL. Although blast-related vibrations are not an issue at BGM, since blasting is not used in the company's mining operations, noise (mainly from BGM's ore processing plant) is an issue of great concern to communities living close to the plant, as explained previously.

RAL's noise, vibration and blast control measures have included fitting of mine vehicles with standard exhaust mufflers to reduce noise to acceptable levels. Ground vibrations are also minimised by the reduction of maximum instantaneous charge through delays between blasts and adequate stemming of blast holes, following Environment Australia blasting guidelines as much as possible.

Although some of the measures above are implemented by AGC and BGL to reduce noise and vibrations associated with their blasting operations (as reported in Chapter 5), unlike RAL which follows specific guidelines (Environment Australia blasting guidelines), none of these two companies undertakes its blasting operations to any specific standards or guidelines. Although no blasting guidelines have been set by the Ghana EPA or Mines Department for the mining companies in the country to conform to, it would be appropriate for the companies to adopt proven standards, as has been done by RAL. Operating to internationally agreed standards or guidelines will not only help the companies minimise the adverse impacts associated with blasting, but also, may help them to be exonerated from blame for exercising 'due diligence' (Bradfield *et al.*, 1996), should a legal action be taken against them in future.

In some of the mining area communities (especially in the BGL mining area where blasting activities were said to have had 'significant' impact on community members), the respondents blamed the shattering of their windows and cracks in their buildings on mine blast-related vibrations. Although the authenticity of such assertions is not easy to prove, by not operating to any specific standards, the companies can not 'confidently' deny being responsible for the problems described above.

7.2.9 *Cyanide Management*

With the exception of BGM which does not apply any chemicals in its mineral development process, all the mining companies in the study area use cyanide in their gold leaching operations. While adequate measures are employed by RAL to minimise the effect of residue cyanide on the environment, a lot still has to be done by BGL and AGC to ensure effective management of residue cyanide from the cyanidation process.

At RAL, large quantities of cyanide-free water from the catchment, upstream of the company's tailings storage area is channelled into the tailings dam. In so doing, the relatively clean runoff water significantly dilutes cyanide in the decant pond area of the dam. Natural degradation of residual cyanide in the tailings dam is also enhanced by discharging the tailings slurry in thin layers and allowing each layer to dry out completely. Again, in preparation for a 'worst case scenario', a cyanide detoxification plant – that uses the INCO-SO_2 process – is installed in the tailings dam, under RAL's Chemical Detoxification Plan. RAL has been monitoring cyanide levels at its water effluent discharge point (where water from its wetland filter enters the Ayensu Creek). As at the time of the field study, the EPAMPL for Total Cyanide had been exceeded only once throughout the company's monthly water quality monitoring over a two-year period [January 1998 – December 1999 – Table A15.1 (Appendix 15)].

Although cyanide is used in BGL's mineral processing operations, no comprehensive programme for the management of residue cyanide – in line with 'best practice' – had been put in place at BGL's mine in the Bogoso area as at the time of the field study. In completing the questionnaire, BGL indicated that leakage of processing chemicals, including cyanide, is minimised through the maintenance of tanks / equipment containing the chemicals within a sealed, bunded area. This sole approach to controlling cyanide pollution is rather 'poor', since not only 'fresh' cyanide, but also residue cyanide resulting from ore processing, can have devastating effect on flora and fauna once discharged into the environment. In the case of AGC, the conclusion that steps to control cyanide pollution were only being 'partially' pursued in the Obuasi area is drawn from their cyanide monitoring results over a two-year period (January 1998 – December 1999) (see Table A14.2 – Appendix 14). In completing the questionnaire, AGC spelled out a number of measures put in place to reduce cyanide pollution in the Obuasi area. According to AGC, the design of its heap leach process was based on the principle of 'self containment', by which under normal operating and weather conditions, there should be no discharge of effluent into the environment. Again the system has been designed in such a way that cyanide-bearing solutions are totally self-contained within the circuit of heap leach pads, solution holding ponds and the gold recovery plant, where used process solutions are eventually recycled and reused. AGC also stated that overflow ponds connected to the heap leach process site have been designed such that they will overflow only after heavy rainfall of an intensity which is expected, on the average, to occur only once in every 10 years. In addition to these measures, the risk of cyanide-bearing solution seeping into the underlying ground was said to have been reduced by underlying the pads with heavy HDPE membrane, over compacted soil beneath which is installed a leak detection system.

Despite all the measures enumerated above, results obtained from the monitoring of cyanide concentrations in water samples from January 1998 – December 1999 by AGC (Table A14.2 – Appendix 14) reveal that the measures employed to minimise cyanide pollution in the AGC mining area and surroundings may not have been effective enough. Over the two-year monitoring period, with the exception of one month, cyanide concentrations of more than 50% of samples analysed each month exceeded the EPAMPL of 1.0 mg l^{-1}. Over the two-year period, 79% of samples analysed had cyanide concentrations above the EPAMPL. In some cases, 30 times the EPAMPL were measured. Of particular concern is the number of occasions when water samples from River Nyam in the Sansu area had cyanide concentrations above the EPAMPL. In fact, 54% of samples collected from the river had cyanide concentrations above the EPAMPL. Usually, during the rainy season pollutant concentrations tend to be diluted to levels far below those encountered during dry months (Salomons, 1995). However, even at the peak of the rainy season (June / July), cyanide concentrations of most samples analysed by AGC (including samples from Rivers Kwabrafo and Nyam) exceeded the EPAMPL.

During the community surveys, many farmers in the AGC mining area complained about the destruction of their crops by cyanide residue when waste water containing the chemical flows through their farms. Even though no scientific investigations have so far been conducted to verify this assertion, AGC's cyanide monitoring results make it difficult to doubt this perceived link between cyanide-bearing wastewater and destruction of crops. One effective and cost-effective method that may be considered by AGC for the recovery of cyanide from its tailings dams and other water-holding points is the CYANISORB® method. This method can help recover about 90% of cyanide from tailings (Stephenson *et al.*, 1995).

7.2.10 ***Tailings Containment***

During the field survey, only RAL and BGL were found to have put adequate measures in place to contain tailings from their ore processing operations. As can be seen from sections 5.3.3.4 (iii) and Table 5.7, RAL and BGL's tailings containment measures are in line with 'best practice' as outlined by Environment Australia (1995d). Although some measures had been taken by AGC and BGM to contain tailings from their ore processing activities, a lot still needs to be done by the two companies for effective management of their tailings.

Steps taken by AGC in its tailings management programme include the use of seepage ponds beside the mine tailings dam to collect seepage flows from the dam. Clarified water from the dam is then recycled for reuse in the processing plant. AGC also reported that its tailings dam was designed to be capable, if properly managed, of containing a 1 in 100 year rainfall event without overflowing, with the expectation that there would be no overflow from the dam into the environment under normal operating and weather conditions. However, a report from a senior staff member of the Adansi West District Assembly that at the peak of the rains AGC discharges water from its tailings dam in the PTP area directly into the Kwabrafo River was confirmed by the Environmental Management Department of the company. However, the company denied the allegation that the water is discharged without treatment. This denial is however questionable, given the number of water samples from Rivers Kwabrafo and Nyam with pollutant concentrations over and above the Ghana EPA maximum permissible limit (see Tables A1 – A7: Appendix 14). Tailings are supposed to be managed in a safe and environmentally responsible manner throughout the life cycle of the tailings facility (The Mining Association of Canada, 1998). One way AGC could manage tailings water at its mines in the Obuasi area is to adopt the approach recommended by Williams (1994). According to Williams, the water storage function should be kept separate from the tailings storage function of tailings dams. Decant water should be removed from the tailings storage as soon as possible, to maximise water recovery and dewatering of the tailings, and to maximise the volume taken up by the tailings and so maximise the life of the storage (Williams, 1994). Another issue of concern at AGC is the absence of a comprehensive tailings monitoring programme. East (2000), for instance, has recommended a regular monitoring of tailings facilities relative to the initial design criteria. Any deviations from operational compliance criteria will then provide early warning of potential problems, and necessary corrective action taken (East, 2000). Again, at least once a year, tailings storage areas should be inspected and reviewed by the original designer or an engineer experienced and competent in the construction and management of tailings impoundments (East, 2000).

At the BGM mine, the tailings resulting from mineral processing do not pose the type of threat to the environment that is encountered at the other mines, due to their ore processing technique that excludes the use of chemicals. This, notwithstanding, due to the location of BGM's mine (in a river basin), steps need to be taken to ensure the long-term stability of the tailings dam, since the collapse of the dam, and consequent discharge of slurry from the dam into the two rivers in the mining area (Rivers Bonte and Jeni) can have devastating consequences on water quality and aquatic life. Unfortunately, no engineering measures have been embarked upon by BGM to ensure the long-term stability of its tailings dam. BGM has to learn from RAL's precautionary measures. After an initial estimate of the water budget in RAL's mining area which pointed to the possibility of excess water accumulating in their tailings dam in the future, a spillway was cut through a low valley to take any excess water from the dam, to safeguard its stability. As an additional precaution, the phreatic water level in the dam is monitored (measured) by the company every year to help assess the effectiveness of the processes / techniques for minimising the amount of water in the dam. As mentioned in section 7.3.1 of this chapter, BGM failed to estimate the water balance / budget of its mining area and its surroundings prior to commencing mining operations in the Tetrem area. Meanwhile, given that the BGM mining area has the same rainfall regime as the RAL mining area, the company should, like RAL, take adequate precautionary measures to minimise the possibility of its tailings dam collapsing in the future through accumulation of excess water.

7.2.11 *Management of Sulphidic Mine Waste and Acid Drainage*

Since the ore deposit at BGM's mine does not contain sulphide ores, sulphidic mine waste and its associated AMD problems are not an issue of concern at BGM. However, at the three other mines in the study area, the presence of sulphide ores makes it necessary for appropriate measures to be taken to minimise the generation of sulphidic mine waste / AMD. While adequate steps (in line with 'best practice') have been employed by RAL to tackle potential AMD problems, measures to minimise AMD generation have only been 'partially' undertaken by AGC and BGL.

Prior to RAL commencing mining operations in the Manso-Nkran area, site testing was carried out in the mining concession to establish the potential of AMD being generated from mine waste rock in the course of mining. The tests included measurement of pH of groundwater around the area containing the ore deposit, and a small-scale heap leach test. Following the results from the tests, the company, which had yet to exploit the transition and sulphide ore zones of its ore deposits as at the time of the field survey, indicated that by the time these two zones will be reached, adequate measures would have been put in place to minimise AMD generation and adverse environmental impacts. AGC, on its part, has been minimising the effect of AMD in its mining area by neutralising excess water from its tailings dams by alkaline chlorination before being discharged into the environment. As pointed out in section 7.2.1 of this chapter, prior to the commencement of its Ashanti Mine Expansion Project (AMEP), AGC failed to undertake a study on the AMD generation potential of the ore body at the AMEP site, to enable the company design appropriate programmes to minimise AMD generation and environmental impacts.

BGL undertook studies on AMD generation potential of its Bogoso gold ore only after AMD problems had started to occur in its mining area. This was after a conclusion was drawn at the end of an environmental audit carried out by the Environmental Advisory Unit (Ghana) Limited (1993) that: 'From a number of analyses that have been carried out for pH, iron and arsenic contents of samples, it has been concluded that a rapid oxidation of sulphide minerals, including arsenopyrite, is taking place.' Since then steps that have been taken to minimise AMD genearation and pollution have included:

- Flooding of mined-out pits not intended to be backfilled, to prevent AMD generation
- Pumping of water from dewatered pits back into the processing plant for reuse or lime-treating it to neutralise it before discharging it to natural water courses
- Capping of waste dumps containing transition and sulphide material with a layer of oxide waste prior to revegetation

The potential for AMD generation at BGL's mine could have been ascertained in advance, and AMD prevention and / or impact minimisation measures designed much earlier if static tests had been conducted to evaluate the balance between acid generation potential and acid neutralising capacity of the ore body in its mineral concession (Paktunc, 1999).

7.2.12 *Environmental Monitoring and Performance*

From the approach to the monitoring of air and water quality in the various mining areas outlined in chapter 5 [sections 5.2.3.4 (vii) – AGC mining area; 5.3.3.4 (ix) – RAL mining area; 5.4.3.4 (ii) – BGM mining area; 5.5.3 (iv) – BGL mining area], it can be seen that 'best practice' (Environment Australia, 1995e) is being 'partially' applied by all the mining companies in their monitoring operations. There is the need for all the companies to incorporate a number of additional measures into their current monitoring programmes for the following reasons:

- With the exception of BGL which has a network of dust monitoring points both within and outside its concession, all the mining companies studied have their air quality monitoring sites located only within their concessions, with none located outside the concessions to act as 'control' sites
- Although BGL has enough air quality monitoring points both inside and outside its concession, only dust pollution is comprehensively monitored at these sites. BGL has no specific environmental monitoring programme in place for SO_2 and As_2O_3 despite the fact that ore processing at BGL involves roasting of sulphide and transition ores (containing pyrites and arsenopyrites) and hence, is likely to be accompanied by emissions of SO_2 and As_2O_3
- Only BGL has an appreciable number of water quality monitoring sites both inside and outside its concession. While none of the water quality monitoring sites of AGC and BGM is located outside their concessions to act as 'control' sites, only 1 of RAL's 22 water quality monitoring sites is located outside its Manso-Nkran concession
- None of the four mining companies has a soil / land pollution monitoring programme (e.g., for early detection of soil contamination with heavy metals, and cyanide pollution) in place. This is an unfortunate situation, given the fact that all four mines are located close to communities dominated by farmers whose crop yields (both in quality and quantity) can be seriously affected by pollution from the mines. These issues need to be addressed by the mining companies in the study area along the lines of 'best practice', to ensure that

appropriate and effective environmental monitoring programmes are in place at the various mines

7.2.13 ***Rehabilitation and Revegetation***

For a successful minesite rehabilitation / revegetation programme, thought should be given to site characteristics including land use, as instanced in the reclamation objectives for an abandoned open-pit mine in Bilbao, northern Spain (Saiz de Omeñaca *et al.*, 1993). The mine, abandoned for several years, is very unattractive and constituted a public hazard because blocks of apartments and other buildings bordered it. Moreover, the abandoned mine is an impediment to the expansion of Bilbao, the most populous city in northern Spain. Possibilities of growth here were limited by natural obstacles due to its location in the Nervion River Valley, which is flanked by steep slopes and surrounded by mountains. Due to the above site characteristics, the objectives of the reclamation programme were to: eliminate hazards to people and property; eliminate a source of pollution, particularly to groundwater; improve the aesthetic quality of the environment; and obtain a relatively level land surface. Another example of factors determining the objectives of landscape restoration projects following mining is provided by a restoration project at an open-cast lignite mine site in the Lower Lausitia, eastern Germany. Here socio-economic transition in the region (brought about by reunification of East and West Germany) was the main driving force behind the specific objectives of the restoration programme carried out in the mining region (Mutz, 1998). The main restoration objective was the regeneration of natural ground and surface water systems in the areas of stream hydrology, water quality and in particular, the physical structure of the water courses (Mutz, 1998). Another important factor that influenced the choice of the rehabilitation objectives was the predicted potential for acidification of polluted waters due to the prevalence in the region of subsoils with high levels of marcacite and pyrite without adequate acid neutralising capacity (Mutz, 1998).

The rehabilitation and revegetation programmes of RAL, BGM and BGL are along the lines of recommended 'best practice environmental management' (Environment Australia, 1995f) for the rehabilitation and revegetation of degraded mine sites. Following initial discussions with communities in their respective mining areas to determine their (communities') preferred post-mining land use in the mining areas, the following measures were being pursued at the three mines as at the time of the field survey:

- RAL – Sequential rehabilitation / revegetation was in progress, with more than half of degraded / devegetated areas rehabilitated and revegetated, and a substantial part of the main waste dump rehabilitated and revegetated
- BGM – Progressive rehabilitation / revegetation was in progress, with some degraded areas already revegetated (in all, 57% of backfilling and recontouring of degraded areas under rehabilitation had been completed, with 11% of mined-out areas revegetated)
- BGL – Sequential rehabilitation / revegetation was in progress, with about 30% of cleared / degraded areas already rehabilitated and revegetated

It is laudable that at each of the three mines above, the rehabilitation strategy had been influenced by the desire of the mining area communities to have the mined lands returned to them in a form suitable for crop production, soon after cessation of mining operations. This, indeed, is a step in the right direction, as pointed out by Burger and Sanchez (1999). According to Burger & Sanchez (1999), in preparing plans for remediation of degraded sites and future land use of the site, it is essential to formally include the perceptions and views of stakeholder groups who will use or be impacted by changes on the site. Understanding the views of these stakeholders should be a prelude to fully integrating community values – including local ecological concerns – into decisions for site use and remediation that will affect the future quality of life for local and regional residents (Burger & Sanchez, 1999). The views of the local or regional population can have a strong influence on whether the final rehabilitation work is judged to be a success or failure. The majority of people have some preconceived idea of what the land in their area should look like. It is this preconception which is largely responsible for adverse criticism of waste dumps, rather than any serious concern over loss of productivity or fears of the effects of mining on surrounding land (Bell, 1996). For instance, the majority of people find local vegetation aesthetically pleasing. The planting of native species on mined land is therefore likely to find favour with many people who have an affinity for the protection of flora and fauna. These beliefs and aspirations of local people should not be disregarded as, in many cases, the success of rehabilitation work is likely to be judged more by such subjective views than by strict compliance with legislative requirements (Bell, 1996). Listening to the concerns and preferences of local communities provides insights into less tangible values that should be addressed in the restoration process, such as the setting of restoration goals that are meaningful to local people (Robertson *et al.*, 2000).

At AGC, rehabilitation and revegetation of degraded areas of its mine site were only being 'partially' executed. Signs of extensive soil erosion could be observed in many areas where mining activities had been carried out in the past. Revegetation of degraded land and gullies to check erosion, sedimentation and land degradation had been concentrated at the 'Bald Hill' area along the Obuasi-Tutuka road. The absence of sequential rehabilitation has led to erosion and development of gulleys in several areas within the concession. In the Ampunyasi and Ahansonyewodea areas, some exploration trenches have been left uncovered. Ideally, the trenches should have been refilled with soil and revegetated immediately after the completion of exploration activities.

7.2.14 *Summary of Environmental Performances: AGC, RAL, BGM and BGL*

It can be seen from Table 7.1 and the discussions in sections 7.2.1 – 7.2.13 that most of the mining companies in the study area need to improve their environmental management practices. On an arbitrary scale of 0 – 2 (with 0= None or little compliance with Best Practice Environmental Management (BPEM); 1= Partial compliance; and 2= Full compliance), RAL scored an average of 1.69 points, followed by BGL (1.17 points), BGM (0.9 points) and AGC (0.85 points). When converted into percentages, it can be deduced that RAL complied with BPEM in 84.5% of its environmental management practices aimed at minimising the adverse impacts of its operations, followed by BGL (58.5%), BGM (45%) and

AGC (42.5%). It is clear from this analysis that with the exception of RAL that has been operating as close as possible to BPEM standards in most of its environmental management practices, all the mining companies studied fall short as far as BPEM is concerned.

To be able to operate to BPEM standards requires a thorough understanding of the mining area environment, mining and mineral processing techniques, and, above all, 'total commitment' on the part of mine managers / management in the region, as outlined in the sections below.

7.3 Geo-Environmental Characteristics of Study Area / Environmental Management Implications

Figure 7.1 shows the geo-environmental factors that obtain in the study area and why they should be vividly understood, for the development of a viable EMS for surface gold mining in southern Ghana. In the sections below, these geo-environmental characteristics – described in detail in Chapter 4 – are discussed in relation to their implications for environmental management by the mining companies in southern Ghana.

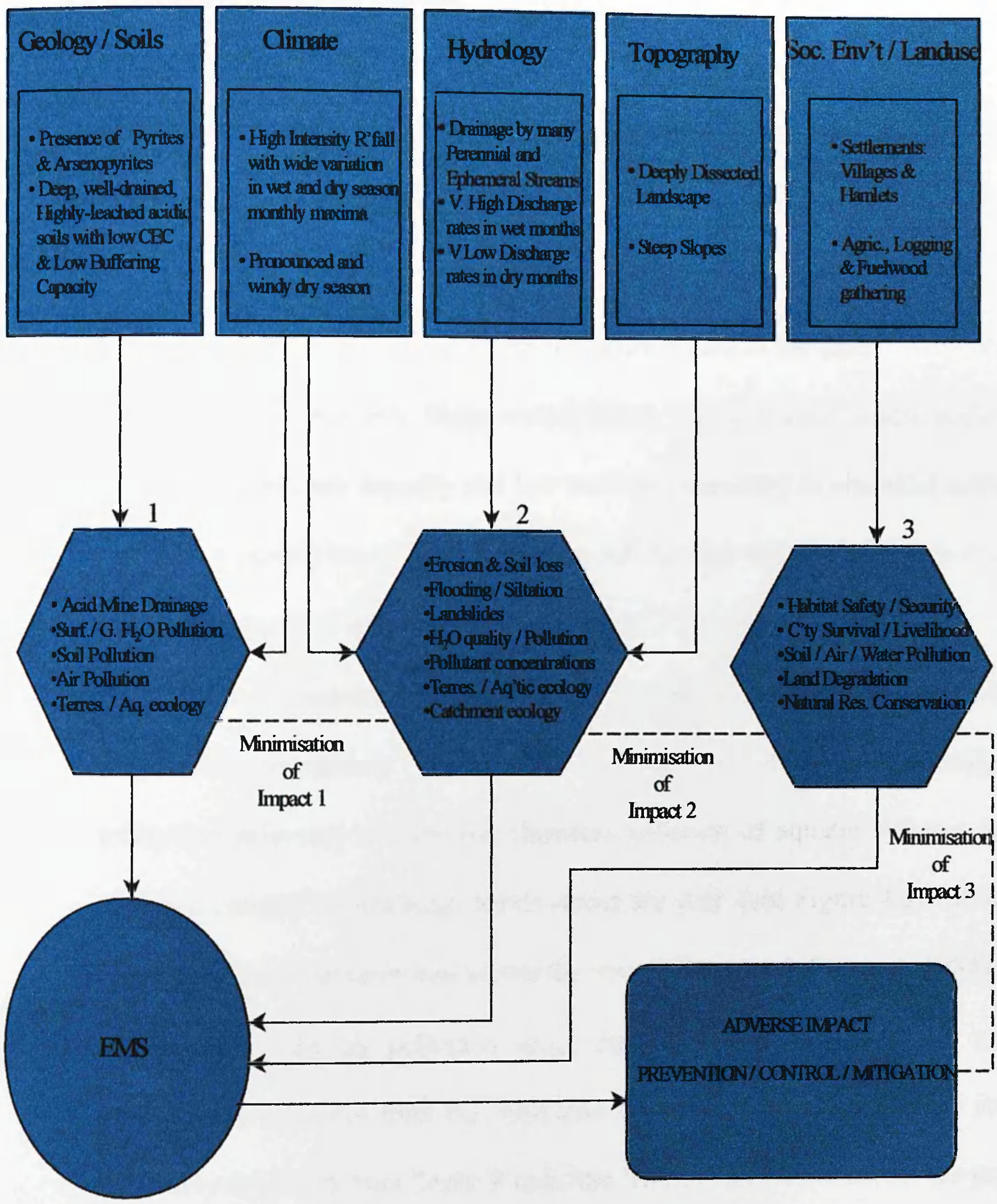

Figure 7.1: Proposed Environmental Considerations for the Development of a Viable EMS for Mining in Study Area

7.3.1 *Geology, Soils and Climate*

Attributes of the geology, soils and climate of the study area that combine to create environmental problems in the area are:

- Presence of pyrites and arsenopyrites in the ore bodies in the area
- Susceptibility of the soils (deep, well-drained, highly leached acidic soils with low cation exchange capacity and low buffering capacity) to chemical pollution and their tendency to act as a 'good medium' through which chemical pollutants can reach groundwater in the area
- Facilitation of chemical reactions that are favoured by large quantities of water (e.g. AMD formation). There could also be difficulties in the design of mitigation measures to minimise chemical pollution of aquatic systems due to the wide variation in discharge levels across the year (see Figure 4.3) which can affect pollutant concentrations across the year (Salomons & Förstner, 1984)
- The tendency for air pollutants (e.g., dust, SO_2 and As_2O_3) to be carried considerable distances from the mine sites in the dry season – when the strong, extremely dry North-East Trade Winds (the 'Harmattan') blow across the region

As depicted in Figure 7.1, the main problems associated with the environmental features enumerated above are (i), Acid Mine Draiange (AMD), (ii), Soil, surface and groundwater pollution, (iii), Air pollution and (iv) Disturbance of terrestrial / aquatic ecology, which are discussed in detail below:

i. *Acid Mine Drainage*

As mentioned in section 7.2.11, with the exception of the BGM mining concession, the ore bodies within the concessions of all the mining companies selected for this study contain sulphide ores (pyrites and arsenopyrites). Waste materials from mining and ore processing containing sulphides can oxidise to sulphuric acid water, which, in turn, may lead to the mobilisation of iron and heavy metals from the leachate stream (Farrel and Kratzing, 1996; Lawrey, 1977). While the metal concentrations are generally toxic to biota, the acid environment is less favourable for many organisms than are near-neutral pH environments (Ledin & Pedersen, 1996). When discharged into the surrounding environment through surface runoff (Horvath & Gruiz, 1996), these heavy metals tend to be concentrated in the humus-rich topsoil (Herbert Jr., 1996), due to the strong adsorptive capacity of humid compounds (Merrington & Alloway, 1994). The heavy metal-laden surface runoff may lead to increased heavy metal content of surface water, and indirectly, the tissues of plants (Horvath and Cruiz, 1996).

Since water is one of the main ingredients for AMD formation in the presence of pyrites and other sulphides (Nicholson, 1994), the rainfall regime in the study area which ensures availability of water in most months of the year (see Figure 4.2) is a cause for concern. In designing preventative measures to minimise the effect of AMD, cognisance should be taken of the wide variation in the wet and dry season monthly rainfall maxima in the study area (see section 4.2.3 – Chapter 4). One approach for inhibiting AMD is the capping of sulphide waste to prevent it from being hydrolysed and oxidised to produce AMD (Orava and Swider, 1996). While this approach can be easily applied in months with relatively low rainfall, the materials for capping should be carefully selected to ensure they will be able to withstand the erosive force of the high intensity rainfall in southern Ghana between May and July. Consideration may be given to the use of a combination of inorganic covers and a sludge cover, which, in addition to their good sealing property (Broman *et al.,* 1991), can result in enhanced soil physical conditions and promotion of a vegetation cover essential to prevent erosion and to make an aesthetical appearance of the mining area (Ledin & Pedersen, 1996). Alternatively, advantage may be taken of the abundance of rain / water in the region by placing waste rock containing reactive materials that can produce AMD under permanent water cover at the earliest opportunity (Morrin & Hutt, 2000) to prevent the oxidation process associated with AMD [see equation after Paktunc (1999) – Page 48] from occurring to any significant extent (Orava and Swider, 1996). To do this however, a thorough study should be conducted of the hydrology of the site to be used for this purpose, especially, where the water table is located, to prevent groundwater contamination. The environmental conditions in the study area make it necessary for the feasibility phase of mineral development in the area to include a critical evaluation and possible use of the following approaches to minimising AMD problems suggested by Orava & Swider (1996) in all future gold mining in the region:

- Methods for reducing the quantities of acid mine wastes produced
- Methods for permanently disposing of reactive mine wastes so as to abate AMD
- Designing short-term AMD control and treatment measures if required

ii. *Soil Pollution and Surface / Ground Water Pollution*

The soils in the study area are highly leached and acidic, with low cation exchange / buffering capacity. This makes the need to prevent AMD – which may plunge the already low soil pH to levels detrimental to plant and animal life – a matter of exigency. In a well-buffered soil, when soil pH reaches about 4, it tends to stabilise despite continuing input of acidity (Rowell, 1994). This buffering of soil pH is not likely to occur in the study area due to the regime of well-drained, highly leached soils in the area, which, like most humid tropical soils, results in complete leaching of all alkaline materials in the soil (Reading *et al.*, 1995). Highly acidic mine waste water, when discharged into the environment untreated, can have devastating effects on plants (including crops) in the study area. This is because when soils become highly acidic, there are associated changes in the following soil properties (Rowell, 1994):

- The amounts of exchangeable Ca^{2+} and Mg^{2+} decrease
- The amount of exchangeable Al^{3+} increases
- The availability of plant nutrients is changed – for example, phosphate solubility is reduced
- The activity of many soil organisms is reduced resulting in the accumulation of organic matter, reduced mineralisation and a lower availability of N, P and S

Usually, aluminium toxicity is the main concern in highly acidic soils, since it has direct effects on plant metabolism, including an interference with the transfer of ions and water through cell membranes (Rowell, 1994). Roots become shattered and thickened, further affecting the plant's ability to take up water and nutrients, particularly phosphate (Rowell, 1994). When the acid waters leave the soil and enter water bodies, they can have damaging effect on aquatic life (Howells and Dalziel, 1992), particularly fish (Rowell, 1994). The threat to fish survival seems to be caused by increased concentrations of Al^{3+} ions and increased Al^{3+} / Ca^{2+} & Mg^{2+} ratios (Rowell, 1994). In drinking water supplies, aluminium can adversely affect human health – especially, in relation to the Alzheimer's disease (Rowell, 1994).

The climatic and soil conditions described above make it necessary for mining companies operating in the study area to give priority attention to environmental management programmes with a focus on preventative, rather than remedial measures. This would help minimise pollution of soils, surface and ground water in the region through AMD, cyanide / other ore processing chemicals, and heavy metals (usually associated with AMD).

iii. *Air pollution*

The presence of pyrites and arsenopyrites in the ore in the study area means roasting of the ore will be accompanied by emissions of SO_2 (from the combustion / oxidation of pyrites – FeS_2) and As_2O_3 (from the combustion / oxidation of arsenopyrites – FeAsS). This inherent property of the ore should be borne in mind from the outset in any future mining activities in the region. It has been ascertained (Nriagu & Pacyna, 1988) that roasting of ore concentrates results in the release of metals in the atmosphere, which may, in fact, be higher, compared with the mining activities themselves. In the 'Bald Hill' area of Obuasi – a hilly area denuded of trees – SO_2 and As_2O_3 emissions from the AGC mining area have been found to be responsible for the destruction of vegetal cover in the area (Amonoo-Neizer & Amekor, 1993). The situation could be made worse by the high rainfall in the region. In Queensland (Tasmania), bare hills in an area totally denuded of vegetation were found to be the result of constant fumigation of the hills by gases containing sulphur dioxide, emitted from a number of copper smelters in the area (Wood, 1991). It was also ascertained (Wood, 1991) that the devegetation of the environment was enhanced by the high rainfall in the area which resulted in the rapid conversion of the sulphur dioxide to acid rain and mist. When sulphide-containing ores are smelted, they emit significant quantities of sulphur dioxide (SO_2) – the principal component of acid rain – into the atmosphere, which, in sufficient amounts, reacts with water to form sulphuric acid which is corrosive and deleterious to natural ecosystems and man-made structures (Hilson, 2000).

Given the high concentrations of gaseous arsenic in the Obuasi area resulting from AGC's mining operations (Amonoo-Neizer & Amekor, 1993; Amonoo-Neizer *et al.*, 1996), adequate steps should be taken by the company not only to help minimise air pollution but also, pollution of water bodies in the area by arsenic. The high concentrations of Total Arsenic in water bodies in the AGC mining area (with as much as 84% of water samples from the Kwabrafo River over a two year period having concentrations exceeding the EPAMPL (see Table A14.3 – Appendix 14) is rather worrying. As pointed out by Woo and Choi (2001), arsenic in water systems is highly undesirable because of its toxicity, even in small amounts. In their study on arsenic poisoning of water bodies near the Gubong Mine (a gold mine in Korea), Woo and Choi (2001) made reference to previous studies in the mining area that established that arsenic found in surface and ground waters in the region was produced from the oxidation of arsenopyrite (FeAsS) in rocks and mining waste after exposure to air.

Extremely dry conditions prevail in southern Ghana from November to early March each year as a result of dry winds (the 'Harmattan') that blow across the region from the Sahara Desert during the period. The wind carries dust, and poor visibility is common in the mornings during this period. Many people also experience catarrh and breathing difficulties during the 5 months. The prevalence of the above conditions in the region makes it necessary for mining companies in the study area to make every effort to reduce air pollution, especially, dust pollution, the most complained about air pollution problem in the region. In future mining operations in the region, mine site facilities should be located with due cognisance to their distance from nearby communities in order to minimise dust pollution, which is an issue in the region even in the absence of mining, as explained above. During the field survey, in all the 16 communities, community members complained about air pollution – especially dust pollution. According to the Department of the Environment [UK] (1995), most dust particles of size greater than 30 microns diameter ('this size of particle comprises some 95% of total dust emissions from mineral workings in general') deposit within 60 – 90 m of their source, under average wind conditions of between 2 and 6 ms^{-1}. Therefore, in the current situation where dust-generating mine site facilities (such as waste dumps and ore processing plants) are located very close (less than 40 m in some cases) to community residential units, suppression of dust at source should be an issue of crucial importance to the mining companies in the region.

iv. *Disturbance of Terrestrial and Aquatic Ecology*

One of the most important issues the mining companies in the study area should be conscious about is maintenance of the ecological balance in the region, in the course of their mineral exploitation activities. The environmental problems described in the sub-sections (ii and iii) above can have serious impacts on terrestrial and aquatic life. As revealed in the literature (Chapter Two) the impacts of gold mining on terrestrial and aquatic ecology can be disastrous when appropriate impact mitigation measures are not taken. In the study area, while research has established a link between mining-related pollution and destruction of vegetal cover (e.g., depletion of vegetation in the 'Bald Hill' area near Obuasi [Amonoo-Neizer & Amekor, 1993]), in many cases (e.g., fish deaths in rivers and streams in the region), such a link has only been speculated. However, there is some evidence (such as 'above threshold' levels of heavy metals found in fish in the AGC mining area (Amonoo-Neizer & Amekor, 1993; Amonoo-Neizer *et al.*, 1996) to suggest that fish mortality in the area could be blamed on pollution from mining-related chemicals. AGC's water quality monitoring results that show extremely high pollutant concentrations in the Kwabrafo and Nyam Rivers is another example that points to the likelihood of a link between fish mortality and pollution. In fact, during the field survey the communities in the study area blamed fish fatalities in the area (described by the communities as 'floating dead fish') on chemical pollution from the mines.

7.3.2 *Climate, Hydrology and Topography*

The folowing characteristics of the climate, hydrology and topography of the study area must be considered, for the design of effective mining impact mitigation measures by the mining companies in southern Ghana: (i) Drainage in the region by many perennial and ephemeral streams; (ii) the occurrence of very high discharge rates in rivers / streams in the wet months of the year, but very low discharge rates in the dry months of the year; and (iii) the nature of the landscape – a deeply dissected landscape with many steep slopes.

The need for climatic and other factors (including those enumerated above) to be factored into any environmental management programme in the study area stems from the fact that put together, they are a good vehicle for:

i. Landslides, erosion, soil loss and siltation;
ii. Chemical pollution / Water quality reduction; and
iii. Disturbance of terrestrial, aquatic and river / stream catchment ecology

The problems above are discussed briefly below:

i. *Landslides, Erosion, Soil Loss and Siltation*

The susceptibility of the study area to landslides, erosion, soil loss and siltation (of rivers / streams) is due, in part, to the combination of heavy rains accompanied by floods, and high velocity runoff from the steep hills in the area. The situation is made worse by the excessive land clearance associated with surface mining operations in the region. Siltation of rivers / streams occurs as eroded soil is carried into the water bodies. During the community surveys, it was reported that many streams in the study area dry up at the peak of the dry season following siltation during the rains that leaves shallow columns of water in the streams a few months after the rainy season. One cost-effective way of minimising the problems above is rehabilitating and revegetating devegetated / degraded mined-out areas as quickly as possible. In this respect, the use of sequential / progressive rehabilitation and revegetation techniques by most of the mining companies in the study area is a step in the right direction.

ii. *Chemical Pollution / Water Quality Reduction*

The discharge patterns of the water bodies in the area (see Figure 4.3) have to be clearly understood for the development of effective control and remedial measures aimed at minimising pollution of these water bodies. This is because the concentration of pollutants – especially heavy metals – vary with discharge rates, as explained below:

Hydrological circumstances, especially discharge, affect heavy metal concentrations in river systems. Metal concentrations are low during periods of high discharge, whereas during low discharge the concentrations may increase by a factor of 5 (Salomons & Förstner, 1984). For metals which show high increases over baseline levels, the influence of discharge can be very strong. This phenomenon may be due to the following effects (Salomons & Förstner, 1984):

- Proportional dilution as the discharge increases assuming a constant load of metals into the river system
- Dilution, as the increased erosion during high discharge (from surface runoff) causes a mixing of contaminated fluvial particulates with uncontaminated soil particles
- Difference in grain size composition – at low discharge, the suspended matter is relatively finer. The coarser particles are settled on the river bed, and, because metals are mainly associated with the finer particles, the dilution by less contaminated coarse particles are absent

However, the reverse of what results from the processes above occurs when the river floodplain and other areas vulnerable to erosion are already contaminated. Here, a high discharge, with erosion, will cause increased levels of pollutants in the river and as a result, the contaminants become more widely distributed in the aquatic environment (Bradley, 1984).

iii. *Disturbance of Terrestrial, Aquatic and River / Stream Catchment Ecology*

Given the susceptibility of the study area to air, soil and water pollution and the concomitant effect of the various forms of pollution on terrestrial, aquatic and water catchment ecology [as explained in section 7.3.1 (iv) of this chapter], the mining companies operating in the region need to be cautious in the design of environmental management programmes. The objectives of their environmental management programmes should include maintenance of appropriate level of ecological balance in the region during their mineral exploitation activities.

7.3.3 *Social Environment and Landuse*

The social environment and landuse characteristics of the study area should be carefully considered in the design of environmental management programmes by the mining companies in the region. A dominant feature of the region's landscape is clusters of villages and hamlets, majority of whose occupants are peasant farmers. Human settlement, an integral part of the landscape, calls for the need for the effective management of air, soil and water quality as well as land / other natural resources that the communities depend upon for their survival and livelihood. Apart from human settlement, major categories of landuse in the area are agriculture, logging, game hunting, firewood and forest products gathering. The above social environment and landuse characteristics make it necessary for the mining companies operating in the study area to be concerned about the following issues, in the course of mining opearations:

- Habitat safety and security
- Land degradation, soil, air and water pollution
- Community survival and livelihood
- Natural resource conservation

The above issues are discussed in detail below:

i. *Habitat Safety and Security*

As mentioned previously, unfilled / unvegetated exploration trenches can be found in many parts of the study area. In addition to this, in the AGC mining area where many mined-out pits are yet to be rehabilitated, a number of open 'inactive' pits are observable. These unfilled / unvegetated pits are a threat to the health and safety of nearby communities. As Al-Hazzan *et al* (1997) rightly pointed out in their description of inactive open pits on mined lands in Ghana: 'People, especially farmers and hunters can easily fall into these pits and get injured or even drowned, as such pits become filled with water.'

One issue of concern raised by some community members during the field survey was destruction of their buildings either through mining-related floods or blasting activities at the mines. While sequential rehabilitation / revegetation programmes embarked upon by most of the mines in the study area can help minimise the effect of floods, most of the mining companies seem to be playing down the effects of their blasting operations. In fact, the companies are of the view that the collapse of buildings of community members may be due to factors other than blasting. Although the companies may be right, the fact that only one company (RAL) carries out its blasting operations to specific standards means there is no 'legal' basis for their insistence that the communities are in the wrong. In fact, in the absence of any guidelines / standards by EPA (Ghana) for mine blasting operations to be carried out to, it may be necessary for the mining companies in the country to adopt acclaimed standards, just as RAL (which has been operating to Environment Australia standards) has done. The British Standards Institution (1993) for instance, has recommended that generally, to prevent structural damage during blasting operations close to residential areas, at a frequency of blasting vibration of between 4 Hz and 15 Hz, a guide vibration speed of 15 - 20 mm sec^{-1} should be adhered to. This means measures such as stemming may have to be appropriately employed to minimise the effects of blast vibrations in mining areas close to communities, to specific standards or guidelines.

ii. *Land Degradation, Soil, Air and Water Pollution*

The community surveys revealed that communities in southern Ghana are worried about the degradation of their land and forest resources which has led *inter alia,* to reduction in their crop yields and increasing distances to their sources of household firewood. Almost every respondent complained about soil, air and water pollution and wished the mining companies in the region would take steps geared towards minimising the various forms of mining-induced pollution in their communities. Land degradation and soil pollution, in particular, should be an issue of concern to the mining companies in the region, given the fact that nearly 40% of the population in the area are peasant farmers (Figure 6.1). Previous studies that found that soils and water bodies in one of the mining areas selected for this study are polluted with heavy metals (Amonoo-Neizer *et al.*, 1996; Amonoo-Neizer & Amekor, 1993) is a cause for concern. Meanwhile, none of the four mining companies studied has a soil monitoring programme in place. This is a serious 'omission' that has to be rectified. Again, given the fact that communities in the study area – just like other communities in the rest of rural Ghana – drink water from rivers and streams directly without treatment, monitoring of the water quality of all natural water sources in the region should be done to 'best practice' standards.

iii. *Community Survival and Livelihood / Need for Preservation of Natural Resources*

The landuse patterns in the study area described in Chapter 4 (Section 4.2.5) show that communities in the area depend mainly on land, rivers / streams, forests and forest products for their survival and livelihood. Therefore adequate measures have to be taken by the mining companies in the region to preserve these natural resources for the benefit of the mining area communities. From the results of the community surveys (Chapter 6) it can be seen that most hunters and fishermen in the study area have abandoned active hunting or fishing activities as a result of drastic reduction in fish and game numbers perceived to be linked to mining activities. This, and the fact that in almost all communities in the study area more than 80% of community members rely on firewood as their main source of household energy (Table 6.6) calls for the need to make concerted efforts for the preservation of community natural resources. In fact, the fuelwood use pattern in the study area does not differ from what obtains in the rest of Ghana, as ascertained by the Environmental Protection Agency of Ghana (1991):

- 'Over 80% of the national energy consumption is derived from wood fuel, which is the sole cooking fuel for a great majority of households'
- 'Of the wood fuels, firewood accounts for over 90% of rural energy use, while in urban Ghana, charcoal makes up about 70% of energy consumption'
- 'There is concern over the continued use of wood fuel owing to the fact that wood for fuel is derived almost exclusively from natural ecosystems, with very little coming from plantations or woodlots'

There is therefore an urgent need for the mining companies in the region to give priority attention to the conservation of community natural resources, especially, forests that provide fuelwood for the communities, in their (companies') mining impact alleviation measures. During the field survey, it was reported throughout the study area that distances to sources of firewood had been increasing over the years, and most of the respondents attributed this to devegetation related to mining operations. Surprisingly, however, relatively few respondents listed 'preservation of community natural resources' among the impact mitigation measures they would like the mining company operating close to them to embark upon. Their stance stems from their thinking that the bulk of their natural resources has been destroyed already, and that the preservation of what remains of these resources is not likely to bring any significant benefits to their communities. This means that the mining companies should give serious thought to the establishment of community woodlots, alongside creating conditions suitable for crop production, for use by the communities in the various mining areas, after cessation of mining operations.

7.4 Proposed Mining Impact Mitigation Measures

As shown in Figure 7.2, the environmental impacts of mining in the study area result from:

- Mining and ore processing activities – as explained in Chapter 5
- Poor and / or ineffective environmental management practices (Table 7.1)
- Inherent environmental attributes of the study area (Figure 7.1)

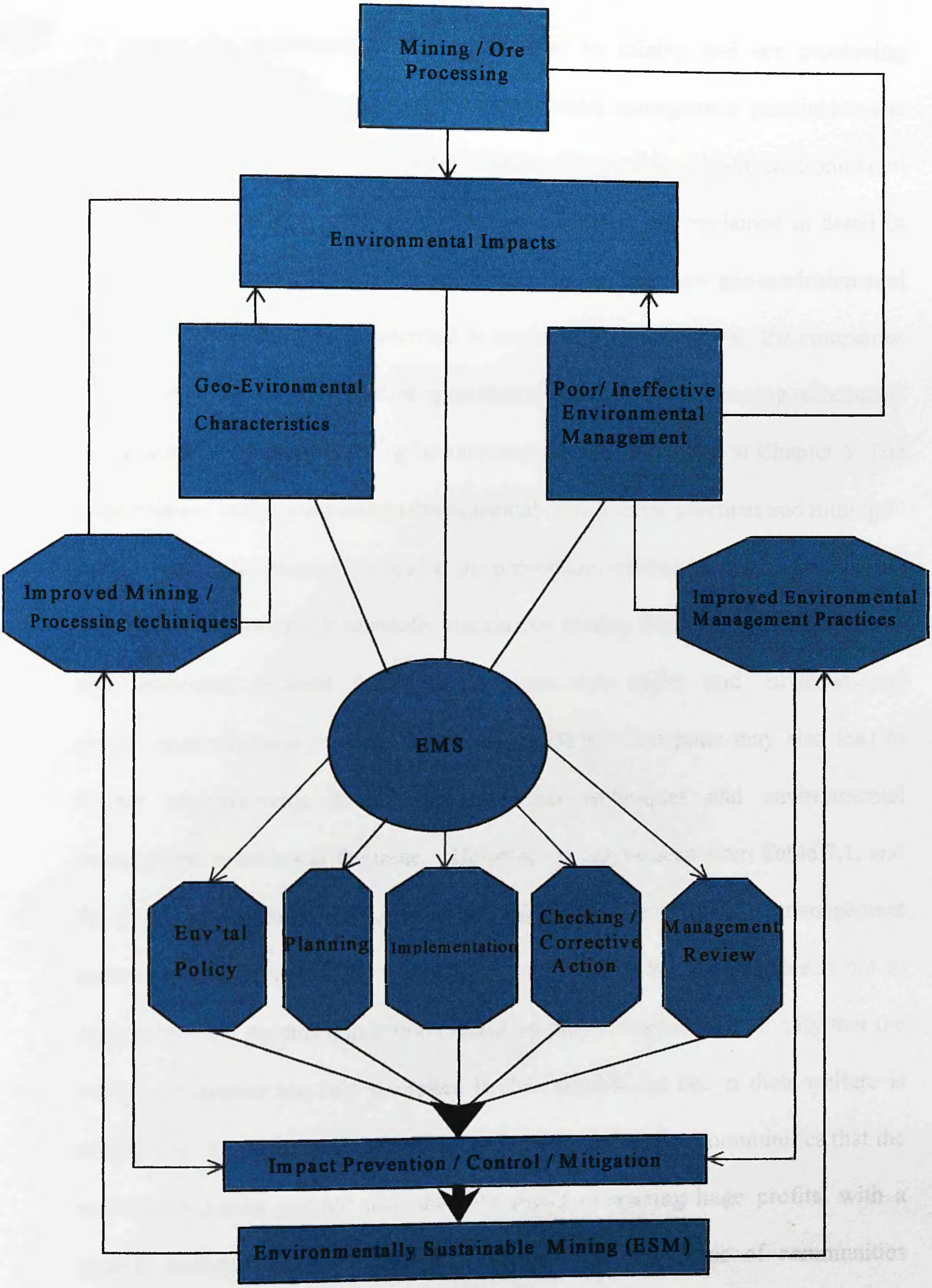

Figure 7.2: Causes of Mining Impacts in Study Area & Current / Proposed Impact-Minimisation Measures

To reduce the environmental impacts created by mining and ore processing activities – coupled with ineffective environmental management practices – the mining companies have been making efforts to improve upon their environmental management practices, at the various phases of mining, as explained in detail in Chapter 5. To minimise the impacts related to the inherent geo-environmental characteristics of the region described in section 7.3 of this chapter, the companies have been taking steps to improve upon their mining and ore processing techniques. These mining and ore processing techniques have been described in Chapter 5. The improvement in the companies' environmental management practices and mining / ore processing techniques is aimed at the prevention, control / mitigation of mining impacts, to ensure environmentally sustainable mining (ESM). Recommendations and associated actions following environmental audits and environmental performance assessments aimed at enhancing ESM at the mine may also lead to further improvements in mineral processing techniques and environmental management practices at the mine. However, as can be seen from Table 7.1, and the discussions in section 7.2, the effectiveness of the environmental management measures pursued at most of the mines leaves much to be desired. This is not to suggest that the general impression created by the mining area community that the mining companies are only interested in their profits and not in their welfare is wholly true. There is a general feeling among the mining area communities that the mining companies operate with the sole object of making huge profits, with a cynical disregard for the well-being, interests and aspirations of communities adversely affected by their operations. In fact, the mining companies have not been resting on their oars as regards the implementation of programmes to mitigate the adverse impacts of their operations, as explained in the early parts of this section.

What seems to be lacking in the companies' bid to minimise adverse mining impacts associated with their operations is the use of a coherent, well-coordinated and integrated approach to environmental management. As pointed out by Warhurst and Bridge (1996), investing in environmental control technology or cleaner production techniques is, in itself, an insufficient condition for achieving and sustaining best practice environmental management. The acquisition, assimilation and operation of an innovative production process in an efficient and clean manner is dependent on the capacity of management to understand, adapt and master the process, and not solely on the technical specifications of plant and equipment (Warhurst and Bridge, 1996). For instance, innovative technological hardware does not by itself ensure a high level of environmental performance, and efforts to achieve environmental best practice need to address the building of managerial capacity in environmental management alongside the development of innovative technology (Warhurst and Bridge, 1996).

The above discourse points to the need for the use of a systematic approach to minimising adverse mining impacts, that combines technology with top management commitment to the principle of environmental sustainability throughout a company's operations. This is where the use of an Environmental Management System becomes crucially important. In fact, the involvement of top-level management in the environmental management process forms part of a good EMS (Martin, 1998). It is being advocated that a viable EMS (specifically, an ISO 14001-based EMS) be developed and used by the mining companies in the study area, for effective environmental management that will ensure environmentally and socially responsible mining in the region. Generally, a good EMS enables companies to pursue high environmental standards both for reasons of environmental sustainability and for the benefit of communities affected by mining operations (Richards and Armstrong, 1996). The ISO 14001 standard provides guidance on EMS requirements based on a simple 'plan-do-check' framework, and focuses on the following major components (Rondinelli & Vastag, 2000):

- The development and adoption of an environmental policy to which senior management is committed
- A planning process that identifies all of the environmental aspects of a facility's operations, legal and other requirements, a set of clearly defined objectives and targets for environmental improvements, and a set of environmental management programmes
- A system of implementation and operation that includes a clear structure of responsibility for environmental management, programmes for training, awareness and competence among all employees of the facility, internal and external communication of the EMS, a system of environmental management documentation, a documentation control system, procedures for operational controls of environmental impacts, and emergency preparedness and response
- Creation of a system of checking and corrective action that includes monitoring and measurement, for reporting non-conformance and for taking corrective and preventive action, of record keeping with regard to environmental management, and EMS audits
- A management review process through which senior management reassesses the suitability, effectiveness and adequacy of the EMS at appropriate intervals to assure continuous improvement

The guidelines' strong emphasis on pollution prevention can save companies money by improving efficiency and reducing costs of energy, materials, fines, and penalties. Certification can not only increase attention to negative environmental impacts but also spread responsibility for maintaining high environmental standards throughout the organisation and, potentially, to suppliers, vendors, and contractors (Rondinelli & Vastag, 2000). An ISO 14001-based EMS plays a critical role in a firm's efforts not only to improve environmental performance but also overall performance. Basically, the presence of an EMS allows a firm to evaluate environmental performance against policy, objectives, and performance targets while seeking performance improvements where appropriate (Melnyk *et al.*, 2003). For instance, in their study of the impact of environmental management systems on corporate and environmental performance of various firms in North America, Melnyk *et al* (2003) found that firms in possession of a formal EMS perceived impacts well beyond pollution abatement and saw a critical positive impact on many dimensions of operations performance. However, it must be pointed out that putting an EMS in place and even obtaining an ISO 14001 certificate does not guarantee good environmental performance. Thus although it is good to have an EMS in place, it is very important to look beyond certificates and rather focus on improved environmental performance leading to decreased environmental impact (Ammenberg & Hjelm, 2002).

7.4.1 *Use of ISO 14001 EMS Standard for the Development of EMS for Mining in Southern Ghana*

It is being suggested that a framework based on the ISO 14001 standard be used for the development of a viable EMS for mining in southern Ghana. However, it must be stated that although the five components / phases of an ISO 14001 standard (see Table 7.2) should be the base for any ISO-14001-based EMS, depending on the type of organisation involved, it is not in all cases that all the elements of a particular component may be required. For instance, of the 17 elements of the ISO-14001 EMS standard, Environment Australia (1995g) has adopted / recommended 12 for the development of EMS in the mining sector, as outlined below.

i. *Policy*

The corporate environmental policy is a concise public statement of the company's intentions with respect to the environment. The company's environmental policy tells the community, and its own employees, the environmental goals and level of performance it intends to maintain. The company should ensure that all proposed actions are consistent with the intent of the environmental policy. The policy should also provide a framework whereby the company can set objectives and future actions, which allow compliance with the environmental policy objectives (Wu and Hunt, 2000). In particular, the policy should include wording covering three key areas (Martin, 1998): compliance with laws and regulations; pollution prevention; and continual improvement (through adoption of BPEM).

Since it is top management that defines the organisation's environmental policy (Martin 1998), their commitment to the implementation of the policy, and indeed, to the entire EMS process is crucially important (Environment Australia, 1995g). In fact, all levels within the organisation will need to be committed to the EMS process (from chief executives down to the line managers). This commitment is often referred to as a change in the organisation's culture with respect to the environment. Such cultural change is possibly the greatest task faced in the successful implementation of an EMS. Without such a commitment the potential benefits to a company from the EMS will not be realised (Environment Australia, 1995g).

ii. *Planning*

One of the most important constituents of the mine planning process is Environmental Impact Assessment (EIA). The first stage in managing environmental issues on a site is to conduct an EIA. This begins prior to the commencement of mining operations and assesses the potential impacts of the mine on the community and the environment (Environment Australia, 1995g). The EIA delineates strategies to minimise and control adverse effects. Hence, the EIA findings form the initial objectives, targets and procedures that the company must achieve or implement. Implementing an EMS ensures the company's performance is sufficient to meet, or exceed the initial requirements identified in the EIA (Environment Australia, 1995g).

Another important aspect of the planning process is community consultation. This should be undertaken before, during and after a mine's operational life, in order to ensure that community concerns are adequately addressed. Continual contact between the community and the company is essential if a level of confidence and trust is to be built up between the two parties. Successful consultation may lead to a decrease in any public criticism and adverse publicity, easier passage of planning and environmental applications, less prescriptive regulatory controls and greater confidence in the company's environmental programme (Environment Australia, 1995g).

Developing objectives and setting targets also form an important part of the planning process. Objectives and targets are developed within the scope of the environmental policy, and should quantify the organisation's commitment to environmental improvement with time (Martin, 1998). Aiming for best practice will mean progressively establishing more stringent targets in order to improve environmental performance, or anticipate potential changes to regulatory requirements (Environment Australia, 1995g).

Effective mine planning requires the development and implementation of an appropriate environmental management plan, which details the method and procedures that the company will use in achieving the stated environmental targets and objectives. The plan should include responsibilities for the various requirements, and should also address both long term targets and longer term objectives (Environment Australia, 1995g; Wu and Hunt, 2000).

iii. *Implementation and Operation*

Once an environmental management plan has been developed, roles, responsibilities and authorities should be defined, documented and communicated in order to facilitate effective environmental management (Martin, 1998). It is necessary for environmental procedures and requirements to be carried out in a timely and appropriate fashion, and the best way to ensure that this occurs is to formally assign responsibilities to personnel with the necessary knowledge and abilities (Environment Australia, 1995g). This may require identification of training needs, so that all personnel whose work may create a significant impact on the environment receive appropriate training (Martin, 1998). This will help provide the workforce with the skills and motivation to implement the EMS (Environment Australia, 1995g). It is also important for the organisation to establish and maintain procedures for (Martin, 1998): (i) internal communication between the various levels and functions of the organisation; and (ii) receiving, documenting and responding to relevant communication from external interested parties. In particular, the organisation should consider processes for external communication of its significant environmental aspects and record its decision (Martin, 1998).

It is important for all environmental strategies, policies, responsibilities and procedures of the organisation to be clearly documented (Environment Australia, 1995g). Details of the various programmes and initiatives carried out should also be documented and retained as part of the EMS programme. EMS documents are often compiled and stored in an Environmental Manual, which is a convenient form to collate and record the various components making up the EMS. Documentation is a useful reference for both management and staff and is preferable in a form which may be provided to external parties such as regulators, concerned citizens, or even company shareholders, as proof of the company's commitment to environmental management (Environment Australia, 1995g). In order to ensure that site operational and emergency procedures are environmentally compatible, it is also necessary for the organisation to identify, review and document procedures that may have an impact on the environment. This process also assists in worker induction, allows an individual worker's experience to be shared with all site personnel and serve as a reference source (Environment Australia, 1995g).

iv. *Checking and Corrective Action*

It is a requirement of an ISO 14001-based EMS for an organisation to establish and maintain documented procedures to monitor and measure, on a regular basis, the key characteristics of its operations and activities that can have a significant impact on the environment. This should include the recording of information to track performance, relevant operational controls and conformance with the organisation's environmental objectives and targets (Martin, 1998). Regular reviews of the company's environmental performance are necessary during the operation and post-operation phases of a project to ensure procedures are appropriate, to satisfy due diligence requirements and to ensure environmental outcomes are being achieved. Environmental performance indicators should be measurable and significant. The reviews should be annual and assess the company's performance against regulatory requirements, internal objectives and targets, EIA requirements and previous audit recommendations (Environment Australia, 1995g).

An ISO-14001-based EMS is required to establish and maintain programmes and procedures for periodic environmental management systems audit to be carried out in order to (Martin, 1998):

- Determine whether or not the EMS conforms to planned arrangements for environmental management including the requirements of the ISO 14001 standard
- Determine whether or not the EMS has been properly implemented and maintained, and provide information on the results to management

The audits help identify existing and potential problems, assess the impacts of waste discharges on the environment and the community, and determine what action is needed to comply with regulatory requirements and company targets. Areas of concern are then prioritised and solutions formulated (Environment Australia, 1995g). These audits are a crucial element in the development of a competent and effective EMS. The quality of such an audit determines the quality of the environmental objectives and hence the desired environmental outcomes of an EMS. Although most mines require EIAs or an equivalent during the planning stage, sight should not be lost of the fact that even in the best of circumstances, conditions vary to some extent from those anticipated and deviations in mine development will take place (Environment Australia, 1995g). When this occurs, mine management must review strategic plans as required and modify company practices to achieve the environmental outcomes sought. An EMS must cater for these changes in long term planning. Procedures are therefore required to review each stage of the mine's development, from inception to closure (Environment Australia, 1995g).

v. *Review*

The ISO 14001 standard requires that top management, at intervals that it determines, review the environmental management system, to ensure its continuing suitability, adequacy and effectiveness. The management review shall address the possible need for changes to policy, objectives, and other elements of the EMS, in the light of the EMS audit results, changing circumstances and the commitment to continual improvement (Martin, 1998). It is very rare to devise at the first attempt, a management system which is not subject to revision. Normally, management systems evolve via iterative changes as deficiencies are identified and corrected. Operations also change over time and the system needs to accommodate this. Periodic internal reviews are therefore a necessary part of the EMS. General areas which should be regularly reviewed are (Environment Australia, 1995g):

- Applicability of the EMS procedures
- Appropriateness of delegated responsibilities
- The adequacy of the reporting system

These should be looked at about one month after each component or procedure is first implemented to correct any obvious deficiencies. Annual reviews are probably sufficient thereafter. The review group should consist of people responsible for environmental management, community liaison and operations. The review group should have experience in environmental auditing. The group should document its findings and present for review and approval, its proposals to solve deficiencies. The changes should be included in the environmental manual and the workforce informed (Environment Australia, 1995g). It is also useful to have an external expert regularly audit fully the site's operations and the EMS. Someone from outside can bring new and more effective solutions, or can identify problems which were overlooked because of familiarity. An external environmental auditing expert in the mining industry, assisted by site staff, is desirable. If possible, it is useful to have staff employed at similar sites on the audit team (Environment Australia, 1995g). Ideally, this external review should occur regularly, say, every two years. The audit team should report deficiencies and possible solutions. Recommended changes to the EMS should be reviewed and accepted by the site manager and relevant staff. The EMS and environmental manual should be amended and everyone made familiar with the changed requirements (Environment Australia, 1995g).

7.4.2 *Framework of Proposed ISO 14001-Based EMS*

In developing each of the five components of the ISO 14001-based EMS for the production of the proposed EMS by mining companies in the study area, it is suggested that due consideration be given to a set of geo-environmental features of the mining area (Figure 7.3), as explained in the sections below:

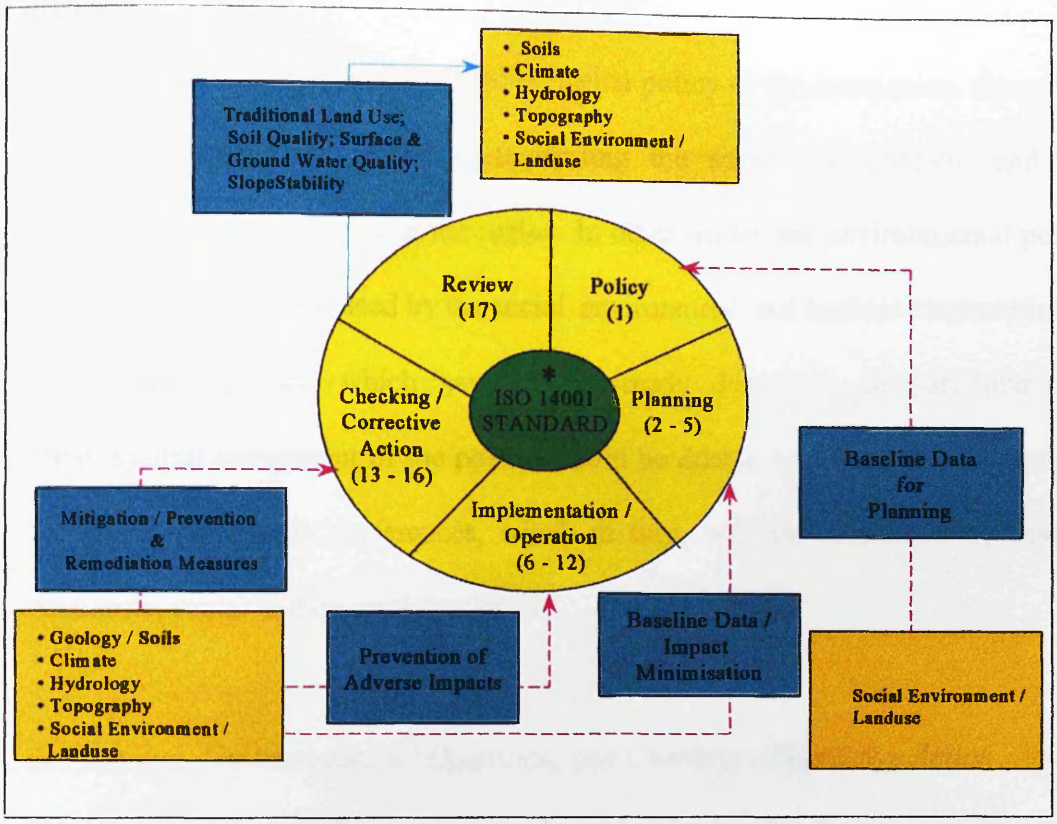

Figure 7.3: Framework of the Proposed ISO 14001-Based EMS for Mining in Study Area

*** Elements of the ISO 14001 EMS Standard (After Martin, 1998)**

Policy

1. Environmental Policy

Planning

2. Environmental Aspects
3. Legal / Other Requirements
4. Objectives & Targets
5. Environmental Management Plan(s)

Implementation and Operation

6. Structure and Responsibility
7. Training, Awareness & Competence
8. Communication
9. EMS Documentation
10. Documentation Control
11. Operational Control
12. Emergency Preparedness & Response

Checking and Corrective Action

13. Monitoring & Measurement
14. Nonconformance & Corrective & Preventive Action
15. Records
16. EMS Audit

Review

17. Management Review

i. *Policy*

It is being proposed that in the environmental policy of the companies, the policy objectives be geared towards safeguarding the social environment, and the traditional landuse patterns in the region. In other words, the environmental policy should be greatly influenced by the social environment and landuse characteristics of the mining area, which have been already described. In particular, the rehabilitation component of the policy should be driven by future landuse options based on community preferences, which in turn, will be influenced by several economic, social and cultural factors

ii. *Planning, Implementation / Operation, and Checking / Corrective Action*

It is suggested that all the environmental problems related to the geo-environmental characteristics of the study area which have already been discussed in the previous sections of this chapter be borne in mind in the development of the above three components of the proposed EMS.

iii. *Review*

During the review of the effectiveness of the proposed EMS and the ability of the environmental management programmes to help meet all legal / statutory environmental requirements, the impact of mining operations on the following features of the mining area should be critically assessed, and appropriate measures taken to ensure they are safeguarded:

- Local climate
- Hydrology

- Soils
- Social environment and land use

7.4.3 *Need for Modification of ISO 14001 Standard*

In addition to the considerations outlined in sections 7.4.1 and 7.4.2, the ISO 14001 standard needs to be adapted, instead of being wholly adopted, for the development of an EMS to suit southern Ghana and other humid tropical environmental areas. It is also important that modifications that can make the EMS adaptable to humid tropical conditions are made known to mine managers in such areas. As rightly pointed out by Guerin (2001), for land users or industries to adopt an innovation for effective environmental management, they need to be helped to understand the benefits and the drawbacks of the innovation. They also need to know what modifications are likely to be needed for adapting and implementing the innovation to their own environmental conditions. This is particularly crucial in the case of the adoption of an Environmental Management System (EMS) due to the fact that lessons learnt from one operation may not necessarily transfer to the culture of a different operation, even within the same corporation (Guerin, 2001).

Two areas of uncertainty are proving to be major obstacles to the widespread adoption of environmental practices by firms and to the efforts of such firms to achieve ISO 14001 certification. The first stems from the ambiguity of the relationship between pollution reduction and profitability. The second arises from the lack of reliable information about the differences in tangible benefits derived from formal, certified EMSs versus those from an informal or less rigorous set of environmentally focused activities (Melnyk *et al.*, 2003). For example, Mbohwa and Fukada (2002) have observed that despite its many benefits and widespread implementation in many parts of the world, it has not been easy to implement ISO 14001 EMS in Zimbabwe. According to these authors, a number of problems and constraints have inhibited its large scale adoption over the years. Mbohwa and Fukada (2002) tried to find out why very few firms (only 3 out of the 80 firms studied) in Zimbabwe had a certified ISO 14001 EMS in place. Their study revealed that the main constraints were technology limitations and the lack of information on the system. This was compounded by the fact that fees charged by consultants [$Z 1.65 million (about $US 30,000)] were not readily affordable. Many of the companies interviewed mentioned cost as a prohibitive factor in their quest to set up an environmental management system (Mbohwa and Fukada 2002). Indeed, implementing a formal EMS or certifying it is a time-consuming and potentially expensive undertaking (Melnyk *et a*l., 2003). Guerin (2001) has emphasised that the adoption of sustainable innovations could be a rather difficult task if not appropriately planned and executed. Using EMS as an example of an innovation in the minerals and energy industry, this author highlights key barriers that had to be overcome by companies in the minerals and energy industry in Australia, when adopting an EMS. Here, Guerin (2001) found that barriers to the adoption of the ISO 14001 EMS included the following:

- Differences in regulatory requirements between locations
- EMS was not perceived as relevant at site level
- EMS implementer too far removed from what site personnel saw as environmental issues

- Inability of ISO 14001 certifying bodies to support companies to sustain EMS and / or fully integrate EMS into business planning
- Changes arising from EMS not initially seen as positive

As far as southern Ghana and other developing / humid tropical countries are concerned, in addition to the problems outlined above, the following conditions make it crucially important for necessary modifications to be made to the typical structure ('requirements') of the ISO 14001 standard prior to its being used for the design of a mine site EMS.

i. *Geo-Environmental Conditions*

Most mining environmental management programmes are based on systems used in developed countries most of which have temperate climatic conditions. Meanwhile, environmental characteristics of such environments differ significantly from those that obtain in typical humid tropical environments. Geochemically, tropical environments are unique. This uniqueness stems from the fact that the terrains here are continuously subjected to extremely high and intense rainfall and drought, with resulting rapid leaching of weathered rock minerals and soils. This characteristic geochemical partitioning results in soil erosion and severe depletion of elements or their accumulation to toxic levels (Dissanayake and Chandrajith, 1999). The conditions described here call for the use of appropriate techniques that can help to ensure soil stability and prevention or control of soil erosion and degradation during mining operations.

Most tropical rainfall is convective, and it has been estimated (Kellman and Tackaberry, 1997) that 40 percent of all tropical rainfalls exceeds 25 mm h^{-1}, a rate considered to be a threshold intensity at which rainfall becomes erosive. Associated with this rainfall regime are risks of erosion and flooding. This obviously has implications for water and soil stability management and monitoring at mine sites in humid tropical regions. Erosion and flooding at mine sites in the humid tropics occur mainly as a result of devegetation, after forests have been cleared to access mineral deposits, construct access roads and staff accommodation, establish processing plants and prepare waste dump and tailings dam sites. Unlike humid tropical environments, temperate areas are estimated to receive only 5 percent of their rainfall in storms exceeding 25 mm h^{-1} (Kellman and Tackaberry, 1997). Another issue worth mentioning is the generally low cation exchange capacity (CEC) of humid tropical soils, which contrasts with most soils in temperate areas dominated by permanent-charge clays with high CEC (Kellman and Tackaberry, 1997). Under the particular heavy rainfall, weathering and soil drainage regimes in humid tropical environments, alkalis and alkaline materials are almost completely leached (Reading *et al.*, 1995), and the soils are thus poorly buffered. With the absence of natural phenomena (chemical reactions in the soil) to restore pH to normalcy following shifts in soil pH levels, prevention and / or control of problems such as AMD becomes very important. The study area experiences high intensity rainfall from March to June, and September to October each year (see Figure 4.2). The soil conditions described above by Reading *et al* (1995) also prevail in the area (see Section 4.1 [Page 141, Last Paragraph]). Therefore serious thought should be given to the geo-environmental characteristics of the study area prior to the design of an EMS for mining in the region, as explained in section 7.3.

ii. *Lack of Adequate Scientific / Baseline Data*

In many developing countries, there is a general lack of adequate scientific / baseline data to help in the design of effective environmental management and monitoring programmes. Reading *et al* (1995), for instance, have bemoaned the inadequacy of knowledge of the humid tropical weather systems in West Africa, as a result of dearth of synoptic stations (particularly over the long term), to record data for monitoring and other purposes. Kakonge (1998) has indicated that the most common obstacle to EIA studies in Africa is lack of sufficient scientific information or data. During the field study at the selected mines, the following observations were made:

- Short-term climatic records at many of the sites
- Lack of detailed hydrological data (surface and ground water)
- Lack of detailed soil survey
- Lack of data on vegetation and wildlife (including fish, birds and mammals)
- Ignorance of local community resource base (e.g. wildlife, fisheries and forest products – including building materials, medicinal plants, fruits and nuts)

The problem of inadequate scientific data in Ghana has been observed by Appiah-Opoku (2001) who expresses concern about outdated demographic and socio-economic data and a general lack of scientific data and baseline information for most environmental attributes in the country. In their recent study on small-scale mining operations around Dumasi in the Western Region of Ghana, Babut *et al* (2003) commented that although mercury contamination in aquatic systems in the area should have been assessed by comparing actual concentrations to 'reference' or background ranges, no regional background values existed for Ghana or even in West Africa.

The situation above (lack of adequate scientific / baseline data) makes the implementation of environmental monitoring and auditing programmes (which are an essential component of an ISO 14001 EMS) in Ghana and indeed, in most humid tropical environments / countries, a rather difficult task. The difficulty is due to the fact there are no 'reference points' to compare monitoring results with, and there is no substitution for the historical data that is lacking. In these circumstances, indigenous ecological knowledge should be tapped, as this can provide some insights into the nature of the ecological systems that existed prior to disturbance. Selected community members (based on their knowledge of the local ecology) can be trained and used in the collection of simple ecological data (e.g. information on water use by the local community, soil erosion, siltation of rivers / streams, physical disturbance to forest ecosystems and trends in animal populations). These locally trained community members may also be used in the monitoring of the impacts of mining on local communities and their environment / natural resources.

iii. *Land Use Characteristics*

A number of issues related to land use would have to be taken into account when designing an EMS for mining in Ghana and in fact, in many developing / tropical countries. One of the issues is how communities here relate to land and natural resources. Due to the high incidence of poverty, and in some cases as part of the culture, the vast majority of the people in many tropical countries live in very close contact with the natural environment, obtaining their food and water directly from the vicinity. This is different from what obtains in the more developed countries of the temperate regions where food and water may be obtained from distant sources (Dissanayaka and Chandrajith, 1999). As explained in Sections 4.2.5 and 7.3.3, communities in the study area and in fact, most areas in rural Ghana depend on surrounding land, water and forest for their food, protein, water, fuelwood and other requirements, for their survival and livelihood. This implies that an EMS for gold mining in the region should be designed with the interests and aspirations of these communities in mind.

In many developing countries, disputes over land often occur between mine management and community groups. This often results from the fact that in many of these countries – such as Ghana – residents have been awarded legal title of large percentages of land. Therefore when they are not adequately compensated or feel cheated, they are likely to initiate all kinds of actions including demonstrations and court actions. Hilson (2002b) has given a comprehensive account of how failure of an Australian mining company – BHP Minerals – to reach an appropriate compensatory agreement with local communities around its Ok Tedi (open-cast copper and gold) mines in Papua New Guinea led to major / protracted disputes between local (native *Wopkaimin*) communities and mine personnel between the mid 1980s and late 1990s. This was after intensive mining operations at Ok Tedi led to displacement of a number of native *Wopkaimin* communities and disruption of their culturally diverse way of life, including their dependence on fishery, forestry and land resources the area was naturally endowed with. The case eventually resulted in an out-of-court payment of compensation totalling nearly

US$ 84 million to communities adversely affected by BHP Minerals' operations in the Ok Tedi area (Hilson, 2002b). One of the reasons why such conflicts are common in developing countries is that here, governmental intervention is often minimal, regulatory frameworks are commonly incomplete, and fewer effective support schemes are in place for community and industrial groups (Hilson, 2002b). It must be pointed out however that it is practically impossible for governments to intervene in such matters if they have a stake in the company that is in conflict with local communities, such as the PNG government, which had a stake in the Ok Tedi mine. In Ghana for instance, the government has a 20 percent stake in AGC (one of the studied mines), and it goes without saying that should there be land use conflicts between the AGC and local communities in its mining area, the government cannot be expected to effectively play the role of an arbitrator in a conflict in which it is a 'culprit'. As Hilson (2002b). rightly suggests, without the full co-operation of governments, most of the responsibility (during such conflicts) rests with the mining companies to resolve land use disputes of all types, and to ensure that mechanisms are in place to prevent further conflicts.

Another (land use-related) source of contention in most mining areas in tropical countries is illegal small-scale mining operations. While licensed small-scale miners have concessions of their own and do not operate within concessions of large-scale miners without permission, illegal (unlicensed) small-scale miners operate uncontrollably within the concessions of large-scale mining companies or in areas prohibited for mining such as forest reserves. Due to the furtive and clandestine nature of their operations, they are not amenable to being monitored, and are responsible for a significant share of mining-related environmental damages

(Aryee *et al.*, 2003). Illegal small-scale mining activities are quite similar in nature in many developing countries, as explained in Section 3.6.2.3 (Chapter 3), and bringing their operations under control can be an uphill task (Hilson, 2002a; Maponga & Ngorima, 2003).

It is a well-known fact that small-scale miners face a host of technical, financial and socio-economic problems that adversely affect productive capacity and compliance with mining, safety and environmental regulations. The sector's disregard of environmental management issues and insensitivity to ecological issues has also been observed (Maponga & Ngorima, 2003). Meanwhile, in this present study, communities in the study area attributed mining-related environmental problems solely to activities of large-scale miners, who have always been in the limelight, and not to activities of illegal small-scale miners, whose operations may even be unknown to local authorities. The above discourse points to the fact that to be able to achieve meaningful outcomes (such as improved environmental performance) in Ghana and other developing countries using an environmental management system, a Western-modelled EMS (such as that based on the ISO 14001 standard) would need to be modified to be able to 'deal with', 'accommodate' or 'manage / monitor' small-scale mining operations – especially, illegal operations.

iv. *Legislation and Statutory Controls / Requirements*

One of the most important requirements of the ISO 14001 Standard is compliance with all environmental management-related legal requirements that apply to the project being undertaken. But Hilson and Murck (2000) have warned that in many instances, performing in line with legislation does not necessarily translate into sound environmental practice. These authors are concerned that much of the developing world is commonly a location for poorly managed mines because of the 'loose' regulatory requirements that 'allow' them to employ a number of rudimentary, low-tech methods in mineral extraction and refining processes. Hilson and Murck (2000) further explain that in much of North America, Europe and Australia, comprehensive environmental legislation has been in place for decades, but in a number of South American, African and Asian countries, environmental laws are still in their infancy, and accompanying enforcement programmes are far from effective. Thus in these countries, a mine operating in line with the legislative benchmark may not necessarily be providing adequate environmental protection.

Kakonge (1998) has observed that in most African countries, the institutional frameworks for establishing or enforcing environmental norms are weak, and in some instances, assisting governments in such countries to put appropriate environmental regulations in place may be the 'way forward'. For instance Placer Dome Inc (Canada's largest gold miner), having realised that environmental legislation is still in its infancy in most of the developing countries it operates in, has assisted governments in these countries to develop environmental regulations to promote responsible mining (Hilson & Murck, 2000).

v. *Cultural / Attitudinal Differences*

The 'Planning' component of an ISO 14001-based EMS requires that a comprehensive EIA – with adequate public participation – be carried out. However, Purnama (2003) has observed that public participation during the EIA process will not effectively work without considering the roots of the public participation culture in society. In Indonesia for instance, lack of a culture of participation and lack of education within the public usually result in minimum public participation in the EIA process (Purnama, 2003). In such situations, relying strictly on prepared guidelines may be of little help, and improvisation may be necessary for the achievement of the right level of public involvement in the EIA process (Purnama, 2003). However, addressing the cultural and other social needs of communities in mining areas can be a challenge of monumental proportions, since mining activities are usually perceived as being heavily environmentally and ecologically damaging, in spite of effective preventative measures that may be in place. Further, accommodating the demands of a community can be highly costly and time-consuming, requiring that the mining company hold a number of public meetings and consultations. In some cases, hiring outside consultation may be inevitable (Hilson & Murck, 2000).

In Ghana, in addition to the above culture-related issues, cognisance should also be taken of the importance rural communities attach to such cultural values as the existence of sacred sites (e.g. sacred groves), their land tenure systems, and their dependence on resources in their immediate surroundings for survival and livelihood.

In fact, due to the problems outlined above, the requirements of the ISO 14001 Standard as they stand, would need some modifications to be able to be meaningfully applied in the Ghanaian context, and indeed, in many other developing / humid tropical countries, as summarised in Table 7.3.

Table 7.3 Proposed Steps for Adapting ISO 14001 EMS Requirements to suit Study Area Conditions

Component of ISO 14001 Standard	Requirements of ISO 14001-Based EMS	Modifications to ISO 14001 EMS Requirements
Policy	Environmental Policy should include wording covering: compliance with laws and regulations; pollution prevention; and continual improvement	Environmental Policy should also include wording on safeguarding against destruction of community natural resources, and satisfaction of needs / addressing concerns of local communities
Planning	Planning should encompass: *Identifying all environmental issues relevant to project *Identifying all legal requirements in respect of project (e.g. EIA) *Designing clearly-stated objectives and targets, quantifying company's commitment to environmental improvement with time *Preparation / use of appropriate Environmental Management Plans (EMPs) for the achievement of set targets and objectives	Planning may also include: *Developing a plan of action on public education (geared towards equipping local communities to participate in EIA, environmental monitoring, etc.) *Identfying and involving community members (including leaders) in determining compensation packages *Funding research or supporting government in the formulation of appropriate environmental management regulations or settting standards *Early identification of / collaboration with small-scale miners (including illegal miners), with possibility of coexistence agreements (including training in sound environmental management practice) *Having own staff trained on EMS design / implementation in the case of poor mining companies (cost-cutting) *Identification / Liaison with community leaders with ability to assist in conflict resolution (pre-emptive step in preparation for potential land use conflicts)

Table 7.3 Ctd.		
Component	**Requirements of ISO 14001-Based EMS**	**Modifications to ISO 14001 EMS Requirements**
Implementation & Operation	During operational phase of project, it is required that: *Environmental management-related roles and responsibilities be assigned to appropriate staff *Appropriate training be provided for staff tasked with identified roles / responsibilities *Communication procedures (both internally and externally) be established and maintained, ensuring flow of information (including environmental aspects of operations) between management and all stakeholders	During this phase of project, consider: *Organising training programmes for selected local community members aimed at equipping them to play a role in the environmental management process (e.g. environmental monitoring / reporting) *Getting involved in the funding of the 'Adult Education Programme' initiated by the Non-Formal Education Division of the Ghana Education Service, at the local level (to improve litearcy levels of community members to enable them participate effectively in mine environmental management programmes) *Identifying and organising appropriate training programmes for (both legal and illegal) small-scale miners (including environmentally friendly mining methods, environmental management and monitoring)
Checking & Corrective Action	The organisation should: *Establish and maintain documented procedures to monitor, and measure (on a regular basis) key characteristics of its operations and activities that can have significant impact on the environment *Assess (Audit) environmental performance against regulatory requirements, and previous audit recommendations *Following environmental audits / performance assessments, modify company practices to achieve environmental actions sought	During this phase of project, consider: *Undertaking projects (such as gauging of major rivers and establishment of synoptic stations) jointly with other mining companies *Funding of research (baseline studies: land and water resources / quality, air quality and demographic studies) *Involve 'local experts' (community members with extensive experiential / ecological knowledge and other company-trained people from the community) in the collection of 'simple' data for environmental management / monitoring purposes

Table 7.3 Ctd.		
Review	Top management (or a team operating under their auspices – such as internal and / or external auditors) should review the EMS to ensure its continuing stability, adequacy and effectiveness	*Selected community members may be consulted during the review of such issues as effectiveness of the EMS in minimising soil erosion, minimising dust and smoke emissions, reducing noise levels, reducing the incidence of flyrocks, etc. (impacts that most community members can easily describe because they can 'see' or 'feel' them) *Due to the nature of the geo-environmental and landuse characteristics of the study area, prioritise assessment of the effectiveness of the EMS in minimising / controlling soil erosion, AMD and sedimentation, and, minimising mining impact on socio-economic lives of surrounding communities and impact on their property and natural resources

** The proposed modifications should be considered for application in addition to, and not as a substitute for, the requirements of the ISO 14001 standard, for the development of a viable EMS for gold mining in southern Ghana and other humid tropical environments*

7.5 Attainment of Environmentally and Socially Responsible Mining in Southern Ghana

Figure 7.4 shows the 'way forward' as regards the path to the attainment of environmentally and socially responsible mining in southern Ghana. An integrated approach that hinges on the ISO 14001 EMS standard is being mooted for adoption or adaptation by the mining companies in southern Ghana. The particular set of

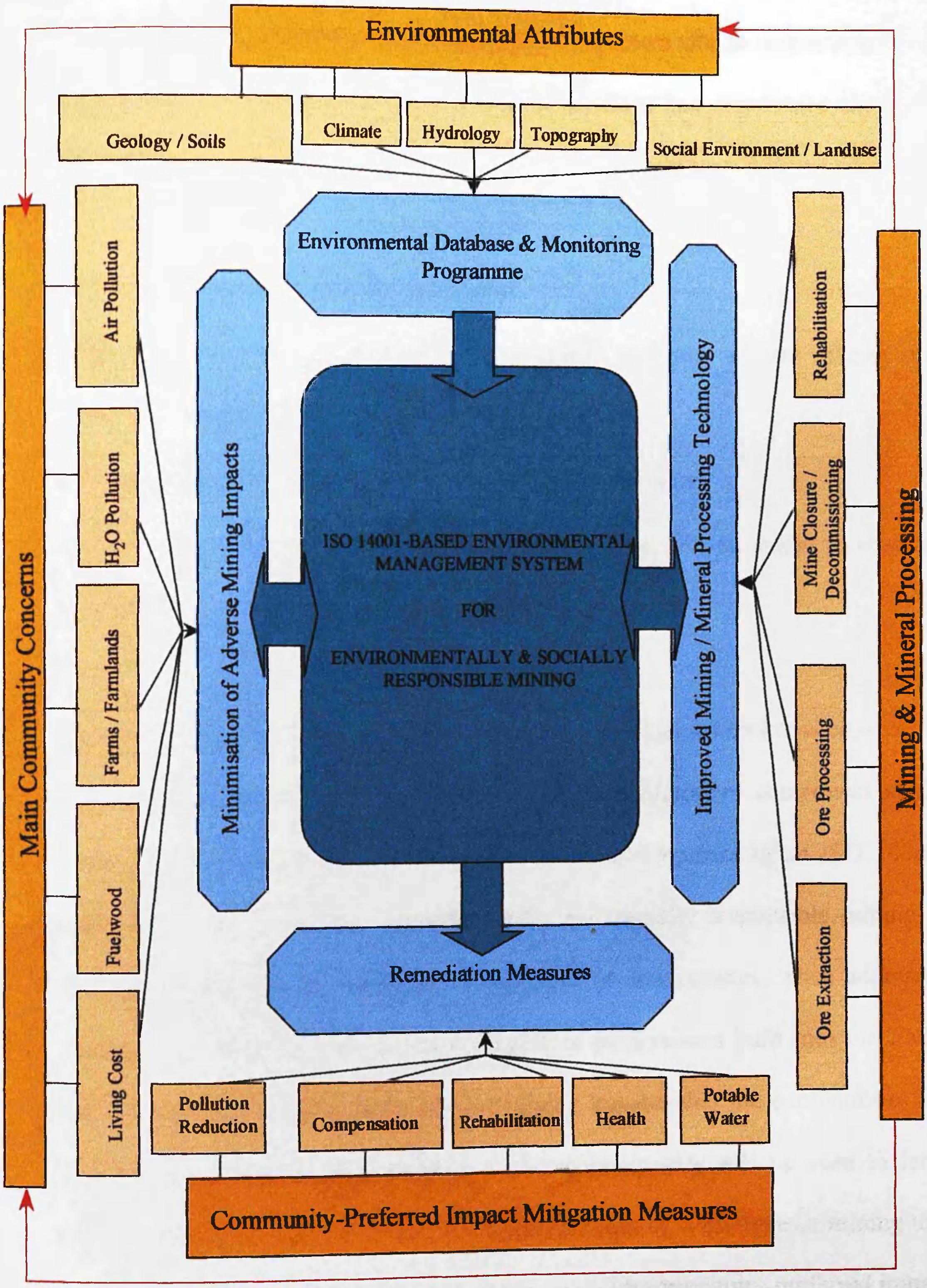

Figure 7.4: Key Issues to be Considered for the Development of an ISO 14001-Based EMS / Attainment of Environmentally and Socially Responsible Gold Mining in Southern Ghana

environmental and socio-economic conditions in southern Ghana means that for the development of a viable EMS for mining in the area, due cognisance should be taken of:

- The environmental attributes of the area
- The main environmental and socio-economic concerns of the mining area communities
- Community-preferred mining impact mitigation measures
- The type of mining and processing techniques that will be suited to southern Ghana's environmental and socio-economic conditions

An environmental database and monitoring programme based on knowledge of the environmental attributes of the region should be an important component of the factors that need to be taken into account in the development of an ISO 14001-based EMS that can ensure environmentally and socially responsible mining in southern Ghana. On the one hand, the concerns of communities, when addressed through appropriate environmental management programmes built into the EMS, will lead to minimisation of the adverse mining impacts that the communities are worried about. On the other hand, the mining companies will be seen to have attained environmentally and socially responsible mining – the type of mining that will also ensure that remediation measures in line with community-preferred impact mitigation measures, are undertaken.

Improved mining and processing techniques at the various phases of mining in the study area / southern Ghana based on environmental management programmes built into the proposed EMS will lead to the attainment of environmentally and socially responsible mining in the region. At the same time, continuous review and audits of the environmental performance of the companies, followed by improvement in their mining / mineral processing techniques (which is an integral part of an ISO 14001-based EMS) may lead to further improvement in mining / mineral processing techniques / technologies by the mining companies.

It must be stressed that environmentally and socially responsible mining can only be achieved after the steps outlined above have been undertaken on a sustained basis by a dedicated and committed management team.

7.5.1 *Costs and Benefits of Implementing an ISO 14001-Based EMS*

In a study to evaluate the cost and benefits of ISO 14001 EMS implementation by firms with EMS certification in Italy, Alberti *et al* (2000) identified the main costs of implementing the system as follows:

i. *Implementation Costs*

These costs cover internal and external human resources and the acquisition of new technology, production resources and tools. Implementation costs vary from business to business and are mainly influenced by the following parameters:

- Organisational structure
- Lack of specific skills
- Availability of internal human resources

- External consultants

ii. *Certification and Audit Costs*

These costs which are paid to an accredited organisation, includes expenses incurred on:

- Environmental analysis
- Development of policy, objectives and environmental management programme(s)
- EMS design
- Audits

iii. *System Maintenance Cost*

These costs result from the following activities:

- Training of workers in both the EMS and the most significant environmental impacts of the production activities
- Defining and testing of emergency procedures
- Monitoring and measurement of environmental aspects of operations
- Public communications
- Monitoring equipment calibration
- Procedures and documentation control
- Preventive and / or corrective actions to avoid non-conformities
- Reporting to update documentation regarding environmental performance
- Internal audit

- Management review to ensure continuous improvement of the system

In the same study, Alberti *et al* (2000) also identified the benefits derived from the implementation of EMS to include the following:

i. *Economically Quantifiable Benefits*

These benefits include:

- Raw materials conservation – this comes from better utilisation and the replacement or recycling of production factors. Reduction of rejects, which have a negative impacts on the environment, encourages optimisation of raw material use
- Productivity improvement – this is closely related to a reduction in the (raw materials) / (final product) ratio, a reduction in rejects and, in general, to a more efficient use of production resources
- Improvement in the production system availability derived from monitoring and more careful maintenance – management plans maintenance and controls in detail, which can help reduce accidental events which could be potentially dangerous to the environment
- Conversion of rejects into products of value – such conversion might regard not only the technological aspects of a reuse of rejects, but also the creation of new markets
- Energy conservation in the production process by rational use of production factors and adoption of more efficient technologies

- Reduction of logistic costs (e.g., materials handling, warehouse capacity and amount of safety stock)
- Reduction of idle times deriving from risk reduction of events that can be potentially dangerous to the environment
- Reduction of transport and / or treatment costs of wastewater or industrial wastes, because the EMS seeks a continuous reduction of residual products
- Improvement of production performance, e.g., changing the process to obtain better control
- Public incentives – mainly state-provided regulatory incentives to companies voluntarily implementing EMS
- Improved access to insurance

ii. *Economically Non-quantifiable Benefits*

These benefits are those that are difficult to quantify with economic indices, and include:

- Better knowledge of the job, of the production system and the consequences that rash procedures could have on the environment
- Liability and risk reduction – EMS defines procedures to identify data on legal requirements and helps prevent sanctions that can derive from potential breaches
- Reduction of site contamination risk by respecting the law (this is a prerequisite for environmental certification) and by systematic control and prevention of dangerous events
- Enhancement of company image towards population and credibility towards the public administration, as the EMS demonstrates to stakeholders that the

company is concerned with environmental issues, making, in some cases, relations easier

- Better product image towards customers – it seems logical to suppose that a good company image can also generate positive effects in the business market
- Human risk reduction – investments in new technologies, which can reduce the risk of accidents, limit the exposure to dangerous substances, or decrease external emissions (such as gases and noise) and reduce health risk
- Enhancement of market opportunities – a certified EMS can give more visibility to a company, represent a qualification for a supply market, or be the criteria in the evaluation of suppliers

7.6 **Recommendations**

While considering the use of a viable EMS for surface gold mining in southern Ghana based on the proposed framework (Figure 7.3), modifications (Table 7.3) and key considerations (Figure 7.4), the following recommendations may be considered for incorporation into Environmental Management Programmes (EMPs) of the proposed EMS by the mining companies in southern Ghana:

- That the companies liaise with relevant government and research institutions (e.g., Water Resources Research Institute, the Forestry Service, the Soil Research Institute, the Geological Survey Department and the Ministry of Lands and Forestry) to undertake comprehensive studies on the current geo-environmental characteristics of southern Ghana

- The results of the above studies should form part of the baseline information to be used in the design of environmental management programmes to minimise environmental and socio-economic impacts of future mining operations in the region
- That, in partnership with staff and students from the Institute of Renewable Natural Resources, School of Mines, the Chemistry and Biology Departments of the Kwame Nkrumah University of Science & Technology research be undertaken to establish *inter alia*, the impact of mining activites on soils, water bodies, forests, air quality, landuse and socio-economic lives of members of the communities in the region
- Evaluation of the landuse options after mine closure / decommissioning should prioritise options that will be of benefit to community members such as establishment of woodlots in rehabilitated pits, tailings dam sites, and rehabilitation of other areas to make them suitable for farming activities
- That the mining companies make a joint effort to establish a few synoptic stations, and measure flow on major rivers in the region to enhance effective monitoring of climatic and hydrological conditions in the area and to help obtain accurate data for modelling, which will lead to accurate predictions for environmental management purposes
- That the mining companies, in partnership with relevant research institutions (e.g., the Soil Research Institute, Forestry Service, the Institute of Renewable Natural Resources and the Chemistry / Biology Departments of the Kwame Nkrumah University of Science and Technology) undertake comprehensive 'species trial experiments', to determine the best species for rehabilitating mine

degraded areas. The studies should include revegetation trials on 'difficult' areas such as tailings sites

- In the above studies, local and community-preferred species should be given greater priority
- That the mining companies that have embarked upon progressive rehabilitation / revegetation initiate research towards elucidating the basic ecological processes such as biomass accumulation, nutrient recycling and fauna recolonization of rehabilitated / revegetated sites. This will ensure that after cessation of mining operations, they will be able to allot specific sites to particular land uses with 'confidence'
- That the mining companies undertake continuous monitoring and assessment programmes (environmental audits) to ascertain whether their environmental performance is in consonance with 'best practice environmental management in mining'. Periodic environmental audits, in any case, are an integral part of an ISO 14001-based EMS

CHAPTER EIGHT

CONCLUSIONS

The community surveys and scrutiny of mining operations in Ghana revealed a number of concerns that need addressing. It must however be stated that much as the mining area communities expressed their views on on-going problems, they could not be said to have been completely objective about some of the concerns raised. For instance, the general criticism that the mining companies operate with the sole aim of making profits, to the neglect of societies adversely affected by their operations, was found to be grossly overstated. For instance, the District Assemblies in the mining areas receive at least 1.5%, while the Traditional Councils in the region receive at least 1%, of the mining companies' gross revenue annually, for community development projects (see Section 1.2 – Chapter 1). This implies that in 1999 for instance (see Table 1.2 – Chapter 1), the Adansi West District Assembly (in the AGC mining area) received royalty payments of about \$ 5.1 million while the Adansiman Traditional Council received royalty payments of about \$3.4 million from AGC. Apart from the mining companies' contribution to community development through these royalty payments, a careful evaluation of the impact mitigation measures at the various mines such as the creation of employment opportunities, and provision of potable water, unveils the reality that the mining companies are concerned about the communities affected by their mining operations. The establishment of a training scheme by RAL backed by 'seed money' to assist farmers to improve upon their socio-economic lives is particularly laudable. However, the assessment of the environmental performance of the mining companies reveals that a lot more needs to be done to safeguard the environment, community natural resources and minimise adverse mining impact on the health, safety and socio-economic lives of community members.

An important concern that has to be raised is the reliability of the community survey data, given the complexity of the factors likely to be responsible for the environmental problems in the study area. The likelihood of the influence of factors other than large-scale mining – such as population pressure, activities of small-scale miners and other anthropogenic activities such as farming – cannot be ruled out or underestimated, as explained in Section 3.6.2.3 (Chapter 3). For instance, although no chemicals are employed by BGM throughout its mining operations, interviewees in the BGM mining area complained about chemical pollution from the company's mining operations. This shows that many community members in the study area lack adequate knowledge of the causes of chemical pollution. There could even be the possibility that the reduction in fish populations in water bodies in the area – as perceived by respondents here – is linked to the high incidence of Total Dissolved Solids (TDS) in water bodies in the BGM mining area (see Appendix 16), leading to reduced oxygen concentrations or causing breathing difficulties among fingerlings or fries. But this is just a matter of speculation. The most worrying of the factors likely to exacerbate environmental problems in the study area is the activities of small-scale gold miners. In fact, a number of factors are preventing implementation of improved environmental practices in the Ghanaian small-scale mining sector. First, a lack of self-generated funding as well as difficulties in securing access to credit facilities are preventing miners from exploring sound environmental management options. These are the major reasons for poor environmental practices being adopted at Ghanaian small-scale mines. The acute shortages of finances in turn leads to a reliance on cheap, haphazard and environmentally unfriendly operational methods. Furthermore, in many instances, the source of financial assistance is the itinerant mineral buyer – legal or illegal – who is only interested in the mineral obtained and not really concerned about the environment. He therefore only provides enough funding for extraction (an activity he may supervise very closely) and not for environmental rehabilitation (Aryee *et al*., 2003). A number of technical factors have also prevented environmental improvement in the small-scale mining industry. There is hardly any systematic exploration over areas in which small-scale mining takes place before exploitation commences. Thus, the majority of miners, as a result of inadequate geological information concerning mineralised areas within their concessions, operate in a trial-and-error manner – a practice that impacts negatively on the environment (Aryee *et al*., 2003). Lack of planning and the consequent failure to incorporate environmental issues at the planning stages of operations results in the creation of substantial environmental liabilities, with no effort made to rehabilitate mined areas. Additionally, there is a widespread lack of knowledge or appreciation of the benefits to be derived from the adoption of appropriate technology, both in terms of improved efficiency of the operation and environmental sustainability. This is more acute amongst illegal small-scale miners, who have little or no access to the technical extension support provided to legal miners (Aryee *et al*., 2003). In fact, studies (e.g. a Ph.D. level research) to evaluate the effects of small-scale mining operations need to be undertaken in the study area, using the approach suggested in Section 3.6.2.3 (Chapter 3).

The community surveys provided a general insight into the nature and types of mining-related environmental and socio-economic impacts of surface gold mining in southern Ghana. Mining companies in rural Ghana could therefore use some of the approaches used in this study as a preliminary step in EIA studies. The approaches included focus groups discussions and personal observations making use of community leaders and elders, and other community members knowledgeable about environmental issues in their communities. Focus groups are particularly appropriate as an exploratory technique where there is little prior research on the topic. An advantage of this technique over the more conventional survey method is that the researcher can use the dynamics of the group to explore awareness, motivations and attitudes in context, depth and detail. This can be done freely, without imposing a conceptual framework (Tunstall, 2000).

It can be inferred from the results of the field studies that if mining in southern Ghana (and in the study area in particular) is to be conducted without putting the mining area communities, their environment and natural resources at risk, then there is the need for the companies to operate to a well-structured EMS. It must however be stated that although multinational mining companies world-wide (e.g., Homestake Mining, Delta Gold, Cambior, Falconbridge and Rio Tinto) have developed, and operate to, ISO 14001-based EMS, very few of them (e.g., Falconbridge; Rio Tinto) have gone one step further by obtaining international EMS certification (Hilson & Nayee, 2002). An important issue worth clarifying is the certification of EMS. Certification of EMS can be expensive and the requirements for conformity can be beyond the means of a small company (Hilson & Nayee, 2002). According to these authors, given the costs of registration, combined with the cost of consultancy expertise, it is unrealistic to assume that any small operation – such as a small mine – would be able to certify its EMS without assistance. However, the good news is that: 'An EMS need not be certified to be effective, and so many mining companies world-wide have opted only to use the ISO standard as a general guideline for developing EMSs at sites' (Hilson & Nayee, 2002). In short, as emphasised by Hammer (1997): 'A company does not require certification to have an effective EMS in place, but that management should follow ISO 14001 when designing and implementing EMSs.' This means that poor mining companies in Ghana can opt to use ISO 14001 guidelines to develop an EMS for mine environmental management, with the ultimate aim of certifying the EMS when their financial position improves.

This study has assessed current environmental management practices and techniques employed by mining companies in southern Ghana against Best Practice Environmental Management (BPEM) in mining. Analysis of the field data collected for the study shows that although much is still left to be desired as regards BPEM in mining in southern Ghana, attempts are being made by most of the companies operating in the region to minimise the environmental and socio-economic effects of their operations. The study has also revealed the important role the EPA Act 1994 (Act 490) is playing in environmental management at mine sites in Ghana. For instance, consistently, RAL, whose operations in the Manso-Nkran area commenced after the introduction of the Act, stands out among the other studied mines as far as BPEM is concerned. The results of monitoring data of RAL and BGM (reported in Appendices 15 and 16 respectively) also show that mining companies in southern Ghana are making an effort to reduce pollution at their mines and surroundings. It is noteworthy that in a recent study on how mining companies in Ghana have been complying with environmental regulations (Domfe, 2003), Teberebie Goldfields Limited (TGL) – a gold mining company in southern Ghana – was found to be making significant progress in the areas of water management, rehabilitation / revegetation, tailings management and pollution control, since formulating its Environmental Management Plan (EAP) in 1998. An interesting finding in Domfe's (2003) study is the fact that significantly, the chief, the assemblyman (government-community liaison person), the youth leader and the local respondents interviewed were quite satisfied with the environmental performance of TGL. In the area of EIA, which the Act (Section 12.1) makes it mandatory for all large-scale mining proponents to undertake, although there is a general lack of local experts to assist mining companies intending to operate in rural Ghana, the companies or the consultants they may employ can benefit immensely from indigenous ecological knowledge. Most of the demographic and socio-economic data in Ghana are outdated, and there is a general lack of scientific data and baseline information for most environmental attributes in the country, including information on groundwater and wetland ecosystems, water, soil and air quality. Indigenous ecological knowledge from communities close to project sites may therefore be used to supplement scanty scientific data and information in the country during environmental assessment studies. This view is shared by Appiah-Opoku (2001). In the same vein, it is being suggested that the Environmental Protection Agency of Ghana make use of the rich experiential knowledge of indigenous communities in Ghana by involving them in the EIA process. In making its decisions on the suitability of a project at a given site, the EPA consults with a cross-sectoral committee of people selected from relevant government agencies.

Appiah-Opoku's (2001) suggestion that this committee could be expanded to include local people with extensive knowledge and understanding of the local ecology and value sets, is indeed laudable. Although the selected community members will not directly make a final decision, their involvement in the EIA process provides an opportunity for the community affected by the development at stake to recognise and understand the critical issues discussed during the review process. The community also learns about and experiences the EIA process and, in particular, the process of participation (Purnama, 2003).

For environmentally sustainable development to be the hallmark of the mining industry in Ghana, it is crucially important that government organisations, mining companies and local communities work to an agreed agenda. For instance, although the EPA has established an inspectorate department that undertakes compliance monitoring, evaluation and enforcement of EIS approval conditions and other provisions of the EPA Act 1994 (Act 490), small-scale mining activities are not registered with the EPA, and hence, are hardly monitored by the Agency. Meanwhile, due to lack of appropriate monitoring equipment, logistics and funds, and inadequate staffing, the Minerals Commission and the Mines Department which regulate the activities of small-scale miners are not able to adequately monitor their operations, including the associated adverse impacts. It is time small scale mining operations were brought under the direct control of the EPA. Alternatively, the EPA should consider working to a specified set of published (and agreed) guidelines, with the Minerals Commission and the Mines Department. Ghana can learn from Nigeria's system for monitoring the activities of small-scale miners, which includes a 'partial' EIA (see Page 77 – Section 2.5.2.1). Currently, only mining concessions that exceed 10 hectares in size have to be registered with the EPA. But it is quite obvious that the impacts of many small-scale mines (mines covering < 10 ha) can be equal (if not greater) than the impacts that one single large-scale mine may create. As observed by Crispin (2003), although the use of simple tools such as gold pans and sluice boxes (in small-scale mining operations) does not cause significant environmental damage individually, where many small-scale mines are agglomerated within small areas, the potential for major problems is multiplied enormously.

While government organisations seek to bring the activities of small-scale miners under control, the mining companies can also make a significant contribution in environmental management in the mining sector by identifying, working together, supporting, and in giving training to small-scale miners. Hilson (2002b) for instance, has suggested that large-scale mine managers establish cohabitation with small-scale miners, a voluntary agreement by which the company accepts small-scale mining operations, but specifies the conditions under which they can continue to operate within their concessions. This may involve setting aside designated areas – especially areas (such as abandoned tailings and waste dumps) that are only economically viable on a 'small' scale for small-scale miners to operate, and specifying what equipment can be used. Additionally, management can establish a programme for training, or involve small miners in existing training activities, where they can be educated about the potential environmental effects of their operations and how to minimise them (Hilson, 2002b). The model example of a successful large and small scale mining partnership is that of Abosso Goldfields Limited (AGL) in the Western Region of Ghana. In November 1996, mine management forged a working partnership with the many illegal gold miners operating on their plot. As Appiah (1998) explains, the company first identified, registered, and regrouped the miners, and then equipped them with AGL identification cards. Further, the company banned the use of explosives, and only permitted the use of basic hand tools for excavation purposes. In Zimbabwe, some large-scale mining companies have also realised the need for the integration of small-scale mining into their programmes so as to minimise environmental damage. Education programmes funded and conducted by some large producers to expose small-scale miners to better gold recovery methods and good environmental management are also in progress at some mines. For example, at Dalny Mine, one of Zimbabwe's largest gold mines, small-scale miners have signed an agreement with mine management allowing them to access water for panning from the mine's pipelines, thus improving productivity and ensuring that panning occurs at specific sites (Maponga & Ngorima, 2003). At another mine, Redwing, small-scale miners have been given permission to rework old dumps with the mine processing their concentrates to recover gold. This eliminates the need for mercury. The mine also takes responsibility for the marketing of the recovered gold and then deducts processing charges and pays the remainder to the small-scale miners (Maponga & Ngorima, 2003). At both mines, management has invested in ongoing programmes for educating the panners on the dangers of using mercury. Through these educational programmes, panners here have come to appreciate the adverse impacts of their gold processing activities on the water table and on drinking water, and have devised new approaches to panning through the construction of special ponds away from rivers. The ponds are manually filled with water, and gold is processed away from rivers, which helps to minimise direct river siltation. From these ponds, free gold is recovered as in a normal river-panning scenario. Another advantage of these ponds is their safety during the rainy season (Maponga & Ngorima, 2003). Large-scale mining companies in the study area can learn from the examples above. In addition to training and working closely with small-scale miners, they can also train and team up with local communities to assist them in environmental assessment studies and in the monitoring of mining impacts.

As an interim measure, government organisations (e.g. the EPA, Mines Department, Minerals Commission and the Ghana Chamber of Mines) can team up to rehabilitate areas degraded or polluted through illegal mining operations, while collaborating efforts to curb illegal mining operations in the country. In this regard, it would be useful for the pilot programme for the reclamation of lands mined by small-scale miners to be continued on a larger scale. Under this pilot scheme initiated by the Minerals Commission and funded by the World Bank Credit, three areas of agricultural land totalling 205 hectares have been recultivated with economic trees and indigenous plants (Aryee *et al.*, 2003).

The main limitation of this study is that it was not possible to have respondents rank impacts in such a way as would have made it possible for their responses to be subjected to conventional statistical analysis. Financial, time and other constraints also made it impossible to conduct social surveys in 'control' communities. These problems set a limit to the extent to which results from the community surveys can be applied, given that most of the data obtained therefrom are based on circumstantial or inferential evidence. For instance, it is not possible to validate or otherwise, similar investigations using the kind of perception-based data obtained from communities in the study area. In spite of these limitations, perceptions of the nature and types of impacts by communities in the study area could be used as a 'starting point' in future scientific investigations on environmental and socio-economic impacts of gold mining in the region. In future research in the study area involving community perception of mining impacts, the suggestions / recommendations offered in Section 3.6.2.3 (Chapter 3) and Section 7.6 (Chapter 7) can also help improve the chances of obtaining data that can be statistically validated.

This study has revealed a number of interesting issues, including how the EPA Act 1994 (Act 490) is contributing to environmental improvement in the mining sector in Ghana. Suggestions have also been made as to how improvement in the EIA process and environmental management and monitoring in the mining sector can be achieved through the use of indigenous knowledge through public participatory strategies. The issue of small-scale mining operations (including illegal operations) and how collaborative efforts involving large-scale miners, small-scale miners and relevant government organisations in Ghana can help bring their operations under control has also been thoroughly discussed. Of particular concern is the activities of illegal (unlicensed) small-scale miners whose operations are difficult to monitor. The large-scale mines could identify, work with, or support them in various ways including allowing them to operate in less-productive parts of their concessions under their (large-scale mines') guidance and control. The mode of payment and amount of compensation paid to mining-affected community members were decried by communities in the study area as being unsatisfactory. The method of compensation used in Fiji (McLeod 2000), which includes payment on uncropped fields is likely to be welcomed by communities in mining areas in Ghana. Mireku-Gyima's (1997) approach to arriving at compensation packages for community members in the Mpeasem area in the Central Region of Ghana (which has been discussed in Section 7.2.2 (Chapter 7) could also be experimented on in the study area and other mining regions of Ghana. Finally, this study has identified and suggested ways for improving environmental performance in the Ghanaian mining sector, focusing on the study area and southern Ghana. The proposed route to the envisaged enhancement in environmental performance at Ghanaian mines is a modified (adapted) ISO 14001-based EMS. The modifications are to help enhance the suitability of the resulting EMS to Ghana's humid tropical- and developing-country environment with environmental, land use other characteristics different to those that obtain in a typical temperate- and developed-country environment where the ISO-14001 Standard was modelled. Given the factors taken into account in developing the proposed 'structures' upon which the development of a viable EMS for gold mining in southern Ghana should be built (see Table 7.3 and Figures 7.3 and 7.4), it is believed that the 'structures' can be used (with minor modifications where necessary) for the development of an ISO 14001-based EMS for environmental management at mine sites in other humid tropical environments. It is however suggested that in addition to seeking to put an appropriate EMS in place, the mining companies endeavour to operate to Best Practice Environmental Management (BPEM) standards within the context of prevailing environmental conditions in their mining area.

It is hoped that by operating to BPEM standards, following the steps proposed for the development of an ISO 14001-based EMS for gold mining in southern Ghana, and implementing the recommendations / suggestions made in this thesis, the chances of mining companies in southern Ghana, (or other mines in similar 'environments') operating in an environmentally and socially responsible manner will be greatly enhanced.

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APPENDIX 1

Beneficiation / Processing of Gold Ore

Beneficiation of gold ore begins with the milling of the extracted ore in preparation for further activities to recover the gold values. Milling operations are designed to produce uniformly sized particles by crushing, grinding, and wet or dry classification. Economics play a part in the degree of grinding or crushing performed to prepare the ore. Other factors include the gold concentration of the ore, the mineralogy and hardness of the ore, the mill's capacity, and the next planned step in the beneficiation of the ore. Run-of-mine ores with very low gold concentrations may be sent directly to a heap leach pile (USEPA, 1994).

Milling begins when the ore material from the mine is reduced in particle size by crushing and grinding. A primary crusher, such as a jaw type, is used to reduce ore into particles less than 150 mm in diameter. Generally, crushing continues using a cone crusher and an internal sizing screen until the ore is less than 19 mm. Crushing in jaw and cone is a dry process, with water spray applied only to control dust. From the cone crusher, ore is fed to the grinding circuit where milling continues in the presence of water. Water is added to form a slurry containing 35 to 50 percent solids. Grinding in ball or rod mills further reduces the ore particle size, as needed. In some cases, ore and water are fed directly into an autogenous mill (where grinding media are the hard ore itself), or, a semiautogenous mill (where the grinding media are the ore supplemented by large steel balls). Between each grinding unit operation, hydrocyclones are used to classify coarse and fine particles.

Coarse particles are returned to the mill for further size reduction (USEPA, 1994). Milled ore, in the form of a slurry, is then pumped to the next unit of operation (Stanford, 1987). Fugitive dust generated during crushing and grinding activities is usually collected by air pollution control device. Most mills use water sprays to control dust from milling activities (USEPA, 1994). After milling, the method employed in separating gold from the gangue depends on the composition of the ore, as explained below:

i. *Oxidation*

Where the gangue is dominated by sulphide ores, after milling, beneficiation of the ore may include oxidation of sulphide minerals and carbonaceous material by roasting, autoclaving or bio-oxidation as explained below (USEPA, 1994):

Roasting

Roasting involves heating sulphide ores in air to convert them to oxide ores. In effect, roasting oxidises the sulphur in the ore generating sulphur dioxide that can be captured and converted to sulphuric acid. Roasting of ores that contain carbonaceous material oxidises the carbon to prevent interference with leaching and reduced gold recovery efficiency.

Autoclaving

Autoclaving (pressure oxidation) operates at a lower temperature than roasting. It uses pressurised steam to start the reaction in which sulphur-bearing minerals are oxidised to the oxide forms. Heat released from the oxidation of sulphur sustains the reaction.

Bio-oxidation

Bio-oxidation of sulphide ores employs bacteria to oxidise the sulphur-bearing minerals. The bacteria used in this technique are naturally occurring and typically include *Thiobacillus ferrooxidans*, *Thiobacillus thiooxidans*, and *Leptospirillum ferooxidans*. In this technique, the bacteria are placed in a vat containing the sulphide gold ore, to feed on the sulphide minerals and ferrous iron compounds of the gold ore. Although more time is required for bio-oxidation, it is considered to be less expensive than roasting or autoclaving.

Once the sulphide ore has been converted to oxide ore, the next stage of the beneficiation process follows the path used in extracting gold from natural oxide ores using gravity concentration or cyanidation techniques as briefly described below (USEPA, 1994).

ii. *Gravity Concentration*

Gravity concentration techniques are used mostly at placer mines, and rely on gravitational forces to suspend and transport gangue away from the heavier valuable mineral.

Appendix 1 Ctd.

iii. *Cyanidation*

The cyanidation technique uses solutions of sodium or potassium cyanide as lixiviants (leaching agents) to extract gold from the ore. Leaching occurs according to the following reaction, with most of the gold dissolving in reaction 2 (van Zyl *et al.*, 1988):

- $4Au + 8NaCN + O_2 + 2H_2O \rightarrow 4NaAu(CN)_2 + NaOH$....................(1)
- $2Au + 4NaCN + O_2 + 2H_2O \rightarrow 2NaAu(CN)_2 + H_2O_2 + NaOH$.........(2)

Cyanidation techniques used extensively in the gold industry include heap or valley fill leaching followed by carbon adsorption (carbon-in-column adsorption), and, Tank Leaching, which may involve either agitation leaching followed by carbon-in-pulp (CIP), or agitated carbon-in-leach (CIL) (Figure A1.1). Heap or valley fill leaching is generally used to beneficiate ores containing less than 0.04 oz/t gold. CIP and CIL techniques, commonly referred to as tank or vat methods, are generally used to beneficiate ores containing more than 0.04 oz/t gold. The various cyanidation techniques are described below:

Heap Leaching

Heap leaching is an efficient way to beneficiate a variety of low-grade, oxidised gold ores. Depending on the local topography, a heap or a valley fill method may be employed. Where level ground exists, a heap is constructed; in rough terrain, a valley may be dammed and filled. Typically, heaps are constructed of lower grade oxidised ores. Depending on the type of ore, it may be sent directly to the heap

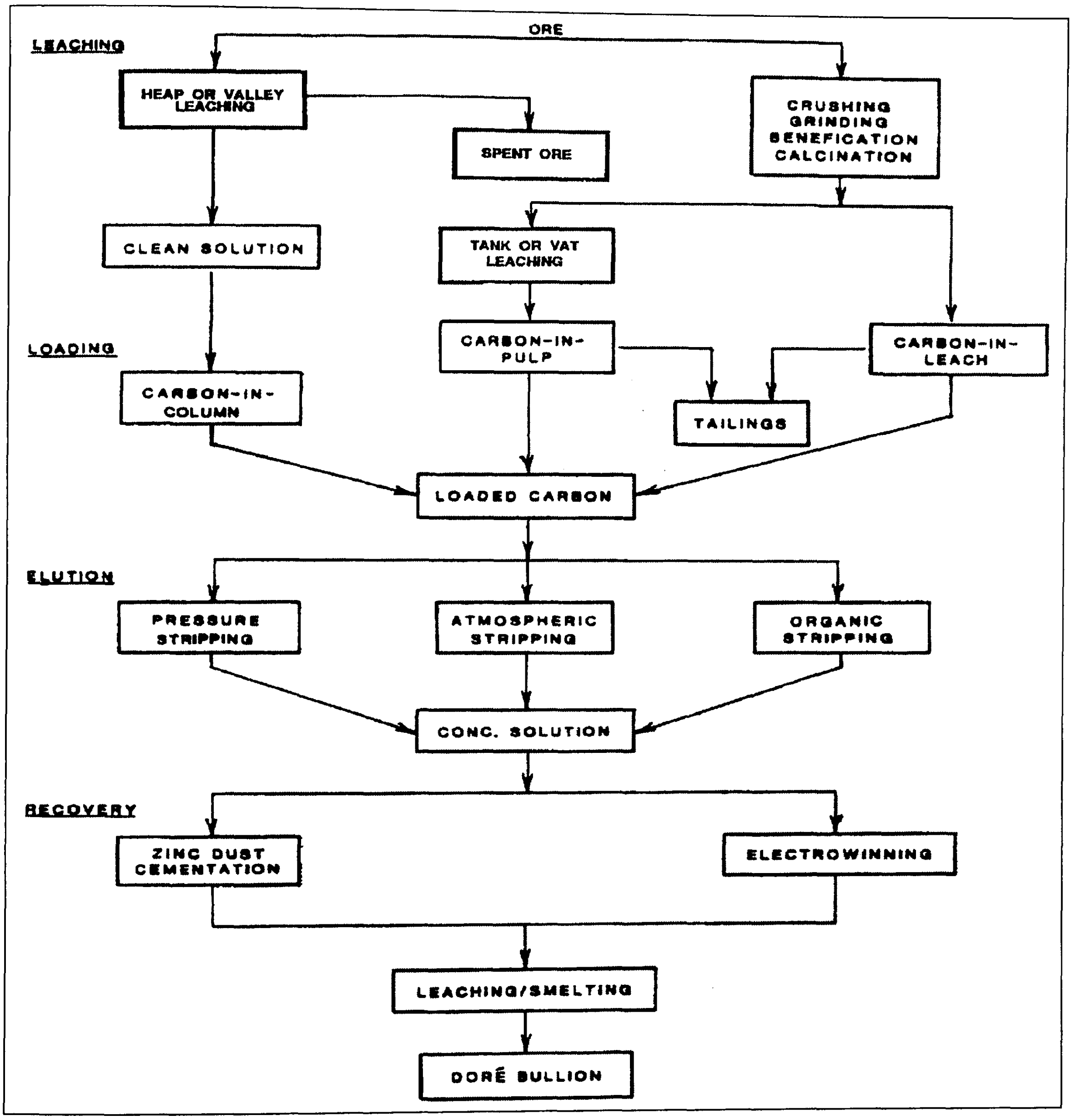

Figure A1.1: Flowsheet for Recovery of Gold Using Carbon Adsorption (Van Zyl et al., 1988)

(run-of-mine ore), crushed, or agglomerated to maximise gold recovery. Figure A1.2 shows a typical heap leaching system. Heap leaching activities may involve some or all of the following steps (U.S. DOI, Bureau of Mines, 1984):

Appendix 1 Ctd.

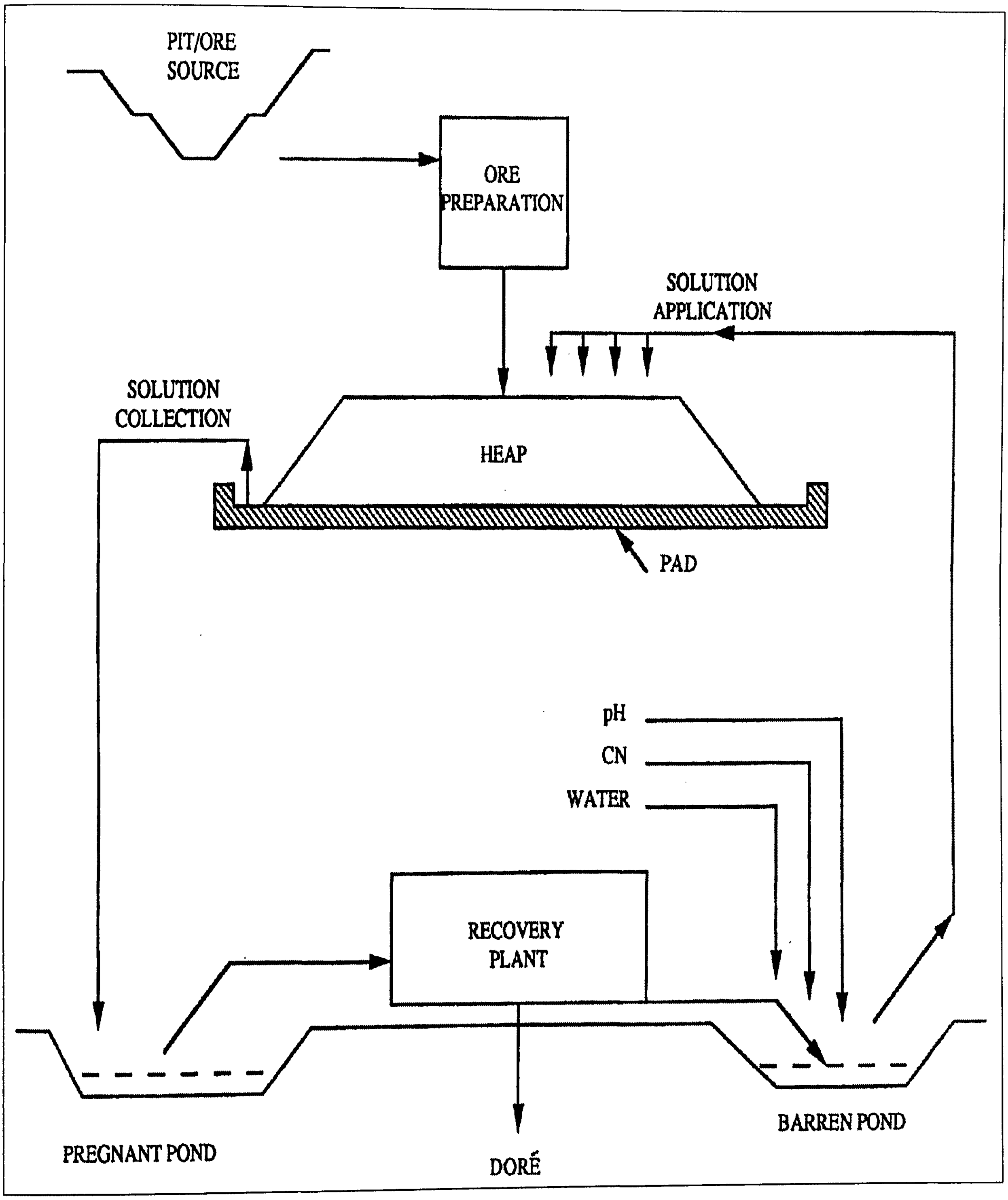

Figure A1.2: A Typical Heap Leaching System (U.S. DOI [Bureau of Mines], 1984)

Appendix 1 Ctd.

- Preparation of a pad with an impervious liner on a 1° to 6° slope or greater for drainage, and extracting ore from the mine site (or alternatively gathering ore from waste piles)
- Crushing and / or agglomeration of the ore to between ½ and 1 inch in size if necessary and cost effective; some operations may leach run-of-mine ore
- Placing the ore on the pad(s) using trucks, bulldozers, conveyor belts, or other equipment
- Applying cyanide solution using drip, spray, or pond irrigation (generally between 0.5 and 1.0 pounds of sodium cyanide per ton of solution)
- Collecting the solution via ditches, piping, ponds and / or tanks

Recovery of gold from the pregnant solution generated by heap leaching is accomplished by carbon adsorption or direct precipitation with zinc dust (Merrill-Crowe Recovery System) (Figure A1.3). These techniques may be used separately or in a series with carbon adsorption followed by zinc precipitation. Both carbon adsorption and zinc precipitation separate the gold-cyanide complex from the noncomplexed cyanide and other remaining wastes, including water and spent ore (USEPA, 1994). The carbon adsorption process in heap leaching uses the Carbon-in Column (CIC) technique. In this technique, the pregnant solution collected from the heap leach pile is pumped from a collection pond or tank into a series of cascading columns containing activated carbon. The solution mixes with the carbon column in one of two methods: fixed-bed or fluid-bed. The fluid-bed method involves pumping pregnant solution upward through the column at a rate sufficient to maintain the carbon bed in a fluid state moving gradually down through the column without allowing the carbon to be carried out of the system. Thus, loaded carbon can be carried from the bottom of the tank and fresh carbon added at the top. The fluid-bed method is the more common of the two methods used in operations adsorbing gold-cyanide values from unclarified leach solutions containing minor amounts of slimes.

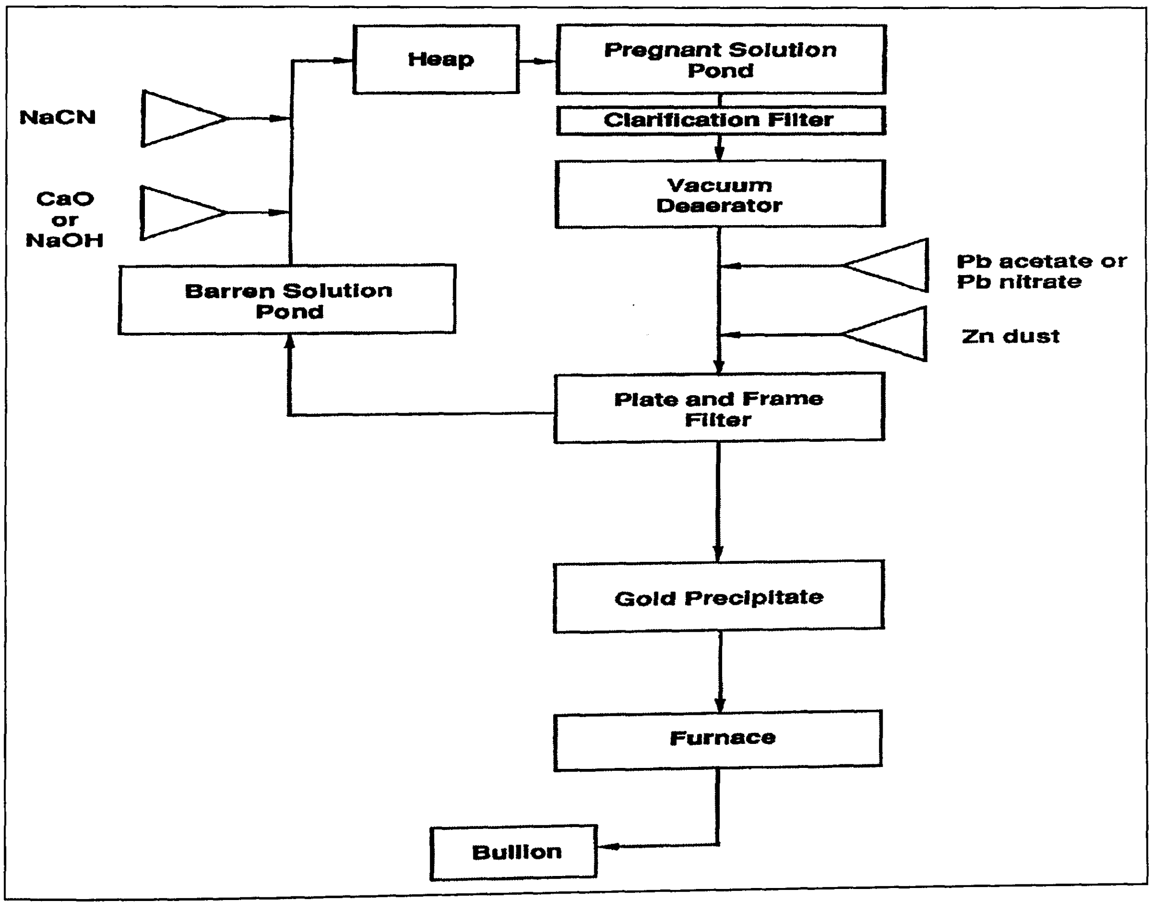

Figure A1.3: Merrill-Crowe Gold Recovery System (Van Zyl et al., 1988)

Because this method uses a countercurrent operating principle, it is often more efficient and economical than the fixed-bed method in adsorbing the gold-cyanide complex from solution (U.S. DOI, Bureau of Mines, 1984).

In the fixed-bed method, the gold-laden cyanide solution is pumped downward through a series of columns. The columns generally have either flat or dished heads and contain a charcoal retention screen as well as a support grid at the bottom. In each vessel, the gold-cyanide complex is adsorbed onto activated carbon granules that preferentially adsorb the gold cyanide complex from the remaining solution as the material flows from one column to the next. The advantage of the fixed-bed method over the fluid-bed method is that it requires less carbon to process the same amount of solution (U.S. DOI, Bureau of Mines, 1984).

In either case, the activated carbon collects gold from the cyanide leachate until it contains between 100 and 400 ounces of gold per ton of carbon depending on the individual operation (U.S. DOI, Bureau of Mines, 1978). The precious metal is then stripped from the carbon by elution: the values can be desorbed from the carbon using a boiling caustic cyanide stripping solution (1.0 percent NaOH and 0.1 percent NaCN). Modifications of this method include the addition of alcohol to the stripping solution and / or stripping under elevated pressure or temperature (40°C to 150°C) (U.S.DOI, Bureau of Mines, 1986). After stripping, the carbon is reactivated on or off site and recirculated to the adsorption circuit. The activated carbon is washed with a dilute acid solution (pH 1 or 2) to dissolve carbonate impurities and metal cyanide complexes that adhere to the carbon along with the gold. Acid washing before the gold is removed enhances gold recovery. Based on impurities to be removed from the carbon and metallurgical considerations, different acids and concentrations of those acids may be used (U.S.DOI, Bureau of Mines, 1986). Usually, a hydrochloric acid (HCl) solution is circulated through 3.6 metric tons of carbon for approximately 16 to 20 hours. Nitric acid is also used in these types of operations, but it is thought to be less efficient than HCl in removing impurities (U.S.DOI, Bureau of Mines, 1986). The resulting spent acid wash solutions may be neutralised with a high-pH tailings slurry, dilute sodium hydroxide (NaOH) solution, or water rinse. When the wash solution reaches a stable pH of 10, it is sent to a tailings impoundment. Metallic elements may also be precipitated with sodium sulphide (Zaburunov, 1989). The carbon is screened to remove fines and thermally reactivated in a rotary kiln at about 730°C for 20 minutes (USEPA, 1994). The reactivated carbon is subsequently rescreened and reintroduced into the recovery system. The pregnant eluate solution containing gold may undergo electrowinning or zinc precipitation. Electrowinning (or electrodeposition) uses stainless or mild steel wool, or copper as a cathode to collect the gold product (USEPA, 1994). After two cycles of electrodeposition, the steel wool is removed and replaced. The depleted stripping solution may then be reheated and recycled to the carbon stripping system. The steel wool or electrowinning sludge, laden with gold value, is fluxed with sodium nitrate, fluorspar, silica, and / or sodium carbonate and melted in a crucible furnace for casting into bullion (USEPA, 1994).

Zinc precipitation (also called the Merrill-Crowe Gold Recovery System) is the most widely used method for gold recovery in heap leaching operations where the gold ore contains large amounts of silver (van Zyl *et al.*, 1988). In zinc precipitation operations, the pregnant solution (or the pregnant eluate stripped from the activated carbon) is filtered using clarifying filters coated with diatomaceous earth to aid in the removal of suspended particles (see Figure A1.3) (van Zyl *et al.*, 1988). Dissolved oxygen is then removed from the solution using vacuum tanks and pumps (van Zyl *et al.*, 1988). This is necessary because the presence of oxygen in the solution inhibits gold recovery (U.S. DOI, Bureau of Mines, 1984). Metallic zinc dust is then combined with the deoxygenated pregnant solution. At some operations, a small amount of cyanide solution and lead nitrate or lead acetate is added. Lead increases galvanic activity and makes the reaction proceed at a faster rate. Zinc precipitation proceeds according to the reaction below; the result is a gold precipitate (U.S.DOI, Bureau of Mines, 1984):

$$NaAu(CN)_2 + 2NaCN + Zn + H_2O \rightarrow Na_2Zn(CN)_4 + Au + H^+ + NaOH \quad \text{.................(3)}$$

The solution is forced through a filter that removes the gold metal product along with any other precipitates. The gold precipitate recovered by filtration is often of sufficiently high quality (45 to 85 percent gold) that it can be dried and smelted in a furnace to make doré (unrefined metals). In cases where treatment is necessary, the precipitate may be muffle roasted or acid treated and calcined with borax and silica before smelting (Weiss, 1985). Following filtration, the barren solution can be chemically treated (neutralised) or regenerated and returned to the leach circuit (Weiss, 1985).

Tank Leaching: Carbon-in Pulp / Carbon-in-Leaching

In tank leaching operations, primary leaching takes place in a series of tanks, frequently located in buildings rather than in outdoor heaps or dumps. Finely ground ore is slurried with the leaching solution in tanks. The resulting gold-cyanide complex is then adsorbed on activated carbon. Carbon-in-Pulp (CIP) conducts the leaching and recovery operations in two separate series of tanks, while Carbon-in-Leaching (CIL) conducts them in a single series. The pregnant carbon then undergoes elution, followed either by electrowinning or zinc precipitation (as described previously). The recovery efficiencies found at tank operations are significantly higher than those found at heap leach facilities. Tank methods recover from 92 to 98 percent of the gold contained in the ore (Zaburunov, 1989).

In tank leaching operations, ore preparation (including grinding, lixiviant strength and pulp density adjustment) and the time required to leach precious metal values varies depending on the type of ore. Oxide ores are typically beneficiated by grinding to 65 mesh and leaching with 0.05 percent sodium cyanide (for a pulp density of 50 percent solids) over a 4- to 24-hour period. Sulphide ores are typically beneficiated by grinding to 325 mesh and leaching with 0.1 percent sodium cyanide for a 10- to 72-hour period (for a pulp density of 40 percent solids) (Weiss, 1985). The two methods employed in tank leaching are briefly described below (Weiss, 1985):

Appendix 1 Ctd.

a. *Carbon-in Pulp (CIP)*

In the CIP technique, a slurry of ore, process water, cyanide, and lime is pumped to the first series of tanks for agitation and leaching. Gold is leached from the ore in the leach tank train. The slurry containing leached ore and pregnant solution is pumped to the second series of tanks for recovery. A diagram of this technique is presented in Figure A1.4 In the second series of CIP tanks, which is similar to the first series, the slurry is introduced into a countercurrent flow with activated carbon. The slurry enters the first tank in the series containing carbon that is partially loaded with the gold-cyanide complex. In the suspended slurry, the activated carbon adsorbs gold material on the available exchange sites. As the carbon material becomes laden with precious metals, the carbon is pumped forward in the circuit toward the incoming solids and pregnant solution. Thus, in the last tank, the low-gold percentage solution is exposed to newly activated and relatively gold-free carbon that is capable of removing almost all of the remaining precious metals in the solution. Fully loaded carbon is removed at the feed end of the adsorption tank train for elution, followed by electrowinning or zinc precipitation (Stanford, 1987) as described previously.

b. *Carbon-in-Leach (CIL)*

The CIL technique differs from CIP in that activated carbon is mixed with the ore pulp in a single series of agitated tanks. Leaching and recovery of values occur in the same series of tanks. A countercurrent flow is maintained between the ore and

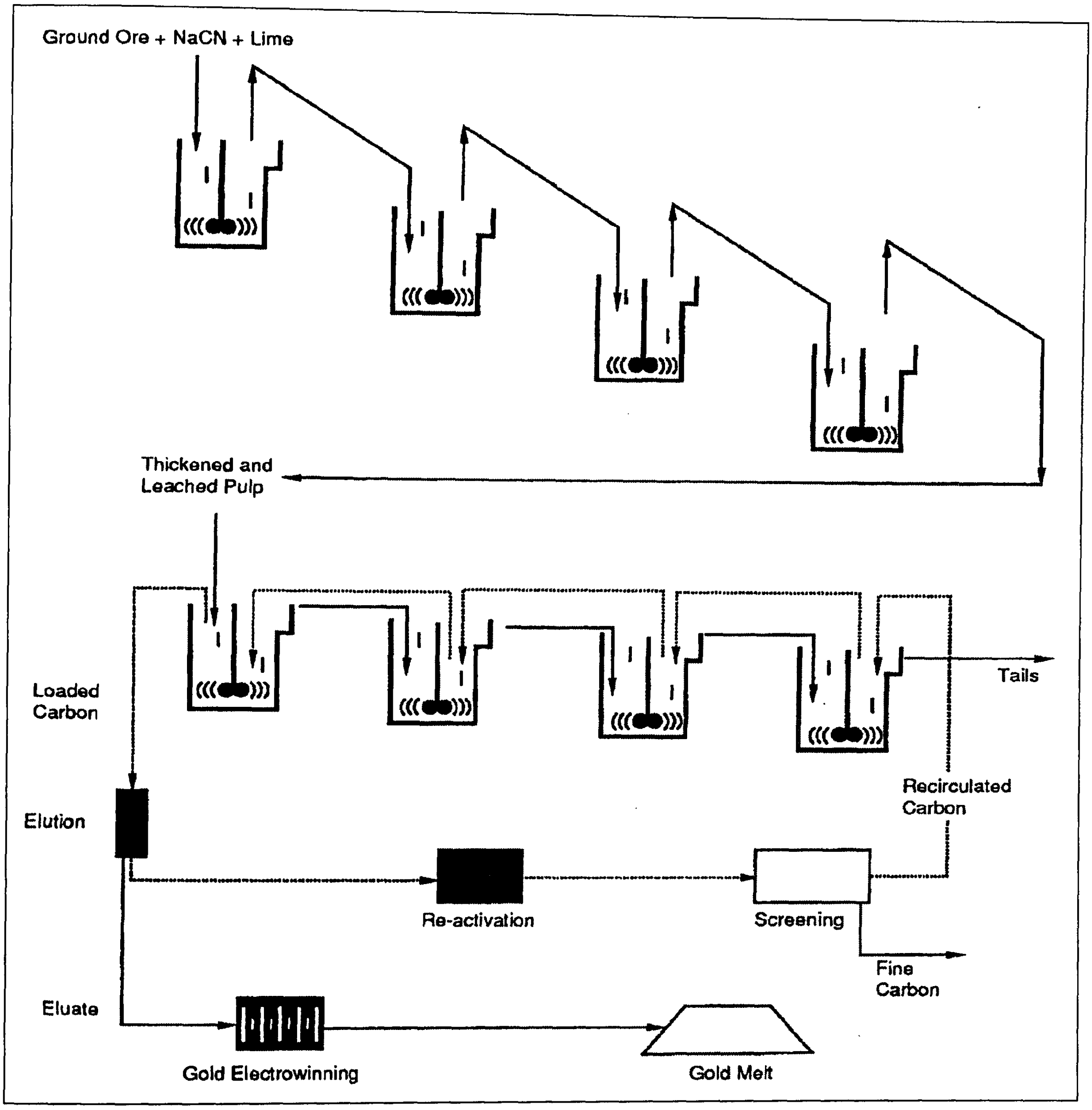

Figure A1.4: Typical Carbon-in-Pulp (CIP) Circuit (USEPA, 1994)

the leaching solution and activated carbon. In the first tanks of the series, leaching of the fresh pulp is the primary activity. In the later tanks, adsorption is dominant as fresh carbon is added to the system countercurrent to the pulp. Adsorption takes place as the gold-cyanide complex mixes with the carbon. As with Carbon-in-Pulp and heap leach operation, the pregnant carbon undergoes elution to remove values.

Appendix 1 Ctd.

The pregnant eluate then undergoes electrowinning or zinc precipitation prior to smelting (Weiss, 1985).

Tank beneficiation methods produce a waste slurry of spent ore pulp or tailings. Spent ore is pumped as a slurry to a tailings impoundment (Stanford, 1987). This solution may contain cyanide, spent ore, lost gold-cyanide complex, gold in solution, and any constituents in the water used in the operation to control shale. Small amounts of gold will continue to be leached in the tailings impoundment and some gold may be recovered as this solution is recirculated back to the mill (USEPA, 1994). Barren leaching solution is either recycled directly back to the beneficiation circuit or sent to a tailings impoundment depending on the amount of solids in solution. This solution may contain spent ore, residual cyanide solution and minor amounts of gold (USEPA, 1994).

Another gold processing method – usually used in small-scale mining operations – is amalgamation. In amalgamation operations, metallic gold is wetted with mercury to form a solution of gold in mercury, referred to as an amalgam (USEPA, 1994). This method of beneficiation is most effective on loose or free coarse gold particles with clean surfaces (USEPA, 1994). Because of its high surface tension, mercury does not penetrate into small crevices of ore particles as sodium cyanide does. Consequently, the ore must be milled finely enough to expose the gold material (USEPA, 1994). Ore preparation consists of grinding, washing, and / or floating the ore. The ore is then fed into a ball mill along with mercury to form an amalgam. The amalgam is then passed over a series of copper plates where it collects. When fully loaded with amalgam, the plate is removed and the amalgam is scraped off. Upon heating the hardened amalgam in a retort furnace, the mercury is vaporised and the gold material remains (USEPA, 1994). The mercury driven off by heating is captured, condensed and reused (Beard, 1987). Alternatively, hot dilute nitric acid may be applied to the amalgam, dissolving the mercury and leaving the gold material (Beard, 1987). Wastes genearated as a result of amalgamation activities consist of gangue in the form of coarse- and fine-grained particles and a liquid mill water component in the form of a slurry. This material is sent to a tailings impoundment (U.S. DOI, Bureau of Mines, 1984).

APPENDIX 2

BPEM in Mining: Mine Planning for Environmental Protection (Environment Australia, 1995a)

Best practice in mine planning requires an understanding of community expectations. To achieve this, mine planners need to understand surrounding land uses, regional and town planning requirements and community aspirations. A constructive community dialogue commenced early in the project can be invaluable in testing project alternatives and obtaining feedback on biophysical and socio-economic issues. It is essential that the developer has an excellent understanding of all the environmental issues and constraints so that they can be considered at the start of the project's planning. This will help to produce the best outcome in terms of economic feasibility, resource utilisation, community acceptance and minimal environmental impact.

Once a mine plan and design is developed, it will be tested and possibly modified during the environmental impact assessment (EIA) phase of the project. The EIA phase will examine the likely impacts of the planned project upon ambient air and water qualities, impacts upon flora, fauna, neighbours, archaeological and heritage sites, and how the wastes and potential hazards will be managed. Fundamental to this evaluation will be consideration of the final rehabilitated site. All the environmental and planning work then needs to be complemented by its implementation through all the phases of the project, from construction through operations to closure.

Appendix 2 Ctd.

As well as the method and rate of mining, some of the issues to be considered during mine planning for environmental protection include the location of the mine infrastructure such as: haul roads; ventillation shaft; tailings and waste disposal areas; ore processing facilities; and township / housing for mine workers. While each mineral deposit is unique, the application of integrated environmental planning procedures is a fundamental component of BPEM. At the mine planning stage, it is useful to consider general environmental constraints such as:

i. *Location of drainage basins, especially*:

- whether there is a substantial upstream catchment that would need diverting around the mine
- whether there is enough water to operate the mine
- classification of receiving water courses
- users of water downstream, and what they use it for
- ecological needs of aquatic and terrestrial flora and fauna

ii. *Surrounding Land Use*

Issues to be considered include the current use of the land surrounding the mine site and its zoning for future development. It must also be ascertained whether there are sensitive land uses in the area that need to be accommodated.

iii. *Visual Exposure*

It must be found out whether the deposit is in a visually prominent area, and whether, if it does, this matters to the local community. What can be done via screen planning or location of facilities to minimise future visual impact should also be considered.

iv. Socio-economic Issues

Measures are available to promote positive aspects of mining while recognising and addressing potentially adverse side effects. This applies to community infrastructure, employment, archaeological and heritage items and land use planning. Although it may not be always possible to accommodate all the aspirations of nearby property owners, nevertheless, close and frequent discussions can usually lead to better outcomes.

APPENDIX 3

BPEM in Mining: Community Consultation & Involvement (Environment Australia, 1995b)

BPEM in mining requires that key potential impacts of the mineral development project be discussed with communities in the mining area. For example, the project developer should discuss with local farmers the proposed water management programme and pollution control facilities at the mine. From such discussions may arise suggestions for improvements. Farmers downstream can then be confident about their water quality. To help establish a sound and ethical relationship with the mining area community, the developer should: begin the consultative process early; listen to community concerns; and identify special interest groups and acknowledge their needs. In particular the needs of the communities should be clearly understood. For instance, in rural areas with an agricultural emphasis or with indigenous communities, issues of concern may include:

- safety of people and livestock
- water pollution
- loss of or disruption of livelihood
- loss of or disturbance of natural values – biodiversity, conservation, vegetation and landscape
- limitations on access to areas of cultural or spiritual significance
- atmospheric emissions, including dust, noise and vibration
- increased traffic levels on rural roads
- loss of or disruption to traditional cultural values

Appendix 3 Ctd.

In the consultation process, it is important to identify the groups, the sub-groups and the people whom the project might affect. It must be borne in mind that communities are not homogeneous groups of people. They comprise sub-groups influenced differently by many factors – age, gender, ethnicity, life values, employment status, religious beliefs, recreational interests and many more. Careful research can identify the profile of local communities and the factors likely to affect project approvals and operations.

APPENDIX 4

BPEM in Mining: Environmental Impact Assessment (Environment Australia, 1995c)

Best practice EIA includes early and comprehensive community and government consultation, co-operation with assessing authorities on Environmental Impact Statement (EIS) guidelines and levels of assessment, and the preparation of an EIS by the company. From this process will flow the company's environmental management plan, which will be part of an overall environmental management system (EMS).

Best practice EIA is the delivery of high quality information. It provides information to the developer and advice to the community, to government and to decision-makers. It requires the developer to describe the proposal in its particular environment, to identify the potential impact on the environment and to describe how the developer plans to manage those effects. It helps the developer to look at alternatives that are prudent and feasible. Where it appears that environmental or social values can not be fully protected, EIA encourages the developer to find ways to lessen the consequences. Commonly, an EIA will identify the issues that the developer has to consider. The assessing authority will draw up guidelines for the EIA. Sometimes it will seek community advice or review.

Of particular importance in the EIA process is information and technical data for assessment of the impact of the project on the following features: the physical environment; ecology; land use; social environment; and infrastructure. Another important aspect of the EIA process is community consultation. Community consultation gives the developer and governments an opportunity to hear public concerns and seek advice early in the planning process. It also helps the company to tell the public about itself and its plans. Community consultation programmes are best developed before the company officially announces the project. The participation of key community representatives and groups in the consultation process is essential. As a rule, the consultation process should begin as early as possible.

APPENDIX 5

BPEM in Mining: Exploration Techniques (Environment Australia, 1996)

Anything less than best practice exploration activities could produce enduring reminders of disturbance, either physically etched into the landscape or in the minds of other land users. To reduce exploration impacts to barest minimum levels, a company should:

- strive to protect the natural and social environments within which exploration is to be conducted – for example, timing of access is important to limit impact of exploration on migratory birds, breeding times for native fauna and farming activities like cropping, lambing and calving
- respect the rights, cultural beliefs and relevant concerns of all parties having a legitimate interest in the land proposed for exploration
- comply with all legal requirements in force in the state or local area where exploration is occurring
- minimise the impacts of exploration wherever possible, consistent with economic and other constraints – as far as practicable, existing tracks should be used during exploration. Grid lines on which to conduct geological, geochemical and geophysical tests can be simply marked by wooden pegs and / or biodegradable flagging tape instead of being bulldozed or cleared
- apply the best practical methods known and available to the company during mineral exploration – for instance, impact of trenching is minimised by costeaning across, rather than down, the slope; by having sloping ends to allow

Appendix 5 Ctd.

animals to escape if they fall into them; and by promptly refilling and revegetating disturbed areas after sampling

- consult with land users, owners, lessees and with government authorities so that statutory and other requirements are known and to encourage two-way communication
- rehabilitate land affected by mineral exploration with the goal of returning it to its pre-exploration land use
- monitor exploration impacts so that less impacting methods can be found and monitor rehabilitation to ensure its long term success

APPENDIX 6

BPEM in Mining: Dust Control (Environment Australia, 1998a; 2000)

Best practice in dust management uses new techniques in monitoring and control, and encourages a pro-active, educative, community consultation approach to dust issues. It uses predictive technology, such as dust modelling coupled with robust climatic and real time data, to identify and mitigate likely dust events.

The success of best practice dust management depends on a joint commitment by management and workers to adopt dust control techniques that recognise and respond to the potential health and environmental impacts, and are sympathetic to the concerns of neighbouring communities. For example, an efficient way of controlling dust emission at the mine site is by the use of EROSIONEX™ – a dust suppression agent . EROSIONEX™ is a non-toxic, non-corrosive, environmentally safe powder developed in Western Australia. It is a synthetic co-polymer that can save 80% of water that normally would be applied to control dust, stabilise soil and establish plant germination and growth. When mixed with water and applied to a surface, EROSIONEX™ forms a tough, water permeable membrane that achieves a cumulative effect of up to 200 mm with multiple application. Tests by the Department of Agriculture, Western Australia confirmed that EROSIONEX™ provides 100% suppression of soil movement in wind speeds below 53 km / hour and 87% reduction in soil movement in wind speed of 65 km / hour. The RT9 Dust Suppressant and RT9 Water Extender are also efficient dust suppressants that have been successfully used. The RT9 Dust Suppressant and RT9 Water Extender have been developed for underground haul road treatment to reduce the dangerous effect of float dust, and for above ground haul roads. RT9 modifies the individual soil particles, allowing for the haul road material to retain moisture while still increasing compaction strength. RT9 conditions the water and allows it to penetrate deep into the normally hydrophobic (water repelling) soil / mineral particles, thereby significantly reducing evaporation rates. Through improved moisture penetration RT9 increases road material compaction which produces an improved road surface. The increased compaction, in combination with reduced evaporation, significantly decreases the amount of float dust produced by vehicles.

Best practice dust management can be achieved by appropriate planning in the case of new or expanding mining operations, and by identifying and controlling dust sources during the active phases of all mining operations. Best practice planning involves: a systematic identification of the potential sources of dust; prediction of the dust levels likely to occur near the mine; evaluating the potential for dust particles to affect human health and the environment; and incorporating dust predictions and control measures into mine planning and design.

A thorough examination of wind and climate, geology and other factors that will effect dust generation and dispersion should be undertaken at the planning stage of mining. Models should then be constructed and run to provide predictive contours of dust levels around the mine. To the degree that is possible, modifications to the mine layout at the planning stage will avoid future problems. Dust control techniques at various stages of mining are described briefly below:

Appendix 6 Ctd.

i. *Land Clearing / Topsoil Removal*

Control options during mining, loading and dumping of topsoil and overburden are generally limited to dust suppression watering. Water trucks and truck-mounted water cannons are commonly used. Scheduling these activities to coincide with favourable winds and weather conditions may be an option. As much as possible, topsoil stripping must be scheduled to occur during periods when soil moisture can be expected to be optimal.

ii. *Blasting and Drilling*

The blasting of near-surface weathered materials that contain a high proportion of fines often creates large dust emissions. The options for controlling dust from blasting are somewhat limited. Watering of the blast area following the charging of blast holes with explosives may assist in minimising dust emissions. Another method that can be effective in protecting areas adjacent to the mine from blasting dust involves delaying blasting under unfavourable wind and atmospheric conditions. This requires some flexibility in blasting schedules, but can be highly effective in controlling dust emissions. Decisions on blast scheduling (to ensure that as far as practicable, blasting is carried out during 'favourable' atmospheric conditions) can be made using computer-generated models that can help predict likely dust dispersion and deposition patterns / concentrations in surrounding areas following blasting. The models use predicted source dust emission rates (based on meteorological data) to produce 'contour' maps of likely dust concentrations in and around the mine at any given blasting period.

iii. *Transportation*

Loading material into haul trucks usually occurs within the pit. Trucks then transport the waste rock and ore to the processing area along designated haul routes. Fugitive dust emissions are produced by the contact of tyres with the unsealed road surface and are affected by the total distance travelled, the silt and moisture content of the road surface and any control practices in use. Control strategies usually involve applying water, or a mixture of water and chemical dust suppressants (for transport), and water sprays and / or enclosures (for loading and unloading procedures).

iv. *Processing, Crushing and Screening*

Dust generated when processing mined materials, primarily occurs as a result of the mechanical handling of the ore. At the ore processing plant the mineral is extracted through a variety of processes that usually involve particle size reduction. The main points that produce dust are dump hopper, primary crusher, transfer points, discharge points, stockpiles (open and enclosed), dry screens, dry loading areas and return strand of conveyer belts. Dust control / minimisation measures are necessary in stockpile and waste rock dump sites / residue disposal areas. Run-of-mine ore stockpiles are rarely enclosed, and where dust control on the stockpiles is necessary, regular watering is the commonly used method. Waste rock dumps and tailings present exposed surfaces that may be prone to wind erosion. It is desirable to plan the waste dump rehabilitation to occur as early as possible in the life of the mine. Establishing the final faces of waste dumps early and revegetating these surfaces will significantly reduce wind erosion . The same principle applies to open areas, i.e., areas cleared of vegetation in advance of mining, waste dumps, etc. Mine planning should aim to minimise open areas and clear vegetation only when necessary for the upcoming mining programme. The early rehabilitation of open areas no longer required for operational purposes will also minimise dust generation.

Tailings are distinct in silt and moisture content from both ore and waste rock, and differ in their potential for particulate emissions from wind erosion. They contain a high proportion of fines, but are usually deposited as a wet slurry. While the tailings remain wet, there is little likelihood of dust problems occurring. Should the exposed surfaces of tailings dry out, however, wind erosion is likely to become a significant problem, especially, in areas with long and windy dry seasons. Apart from creating nuisance dust, dry tailings surfaces may produce dust containing reactive salts or high metal content. Best practice tailings dust control / management involves appropriate planning and design of the impoundment and the associated water circuit in order to accommodate both seasonal events and the decommissioning phase. Most regulatory guidelines and community expectations relating to decommissioning of tailings storage areas favour placing a cover of rock and / or soil over the surface of the tailings and establishing vegetation. As this approach can incur very high costs, appropriate provision must be built into financial planning for the mine. Alternative methods which still offer long term dust mitigation and may meet community expectations in less populated regions include *in situ* inducement of permanent crusts that are resistant to erosion.

APPENDIX 7

BPEM in Mining: Water Management (Environment Australia, 1999)

Best Practice minesite water management requires the use of a minesite water management plan (MWMP) which addresses the impact of:

- mining operations on the water flow and water quality processes of the hydrological cycle, i.e., the environmental impacts associated with the 'risk exposure' of hydrological processes to mining activities
- the hydrological cycle on mining operations, i.e., the 'risk exposure' of mining activities to hydrological processes. Examples include the effects, such as lower productivity and profitability, of floods or droughts on mining activities

An MWMP must be prepared in consultation with regulatory agencies and community representatives such as catchment management committees and downstream landholders. An MWMP needs to adopt a whole-of-mine approach that embraces the four phases of a mining operation: exploration, design and development, operation and decommissioning. The best way to realise the multiple objectives of an MWMP is comprehensive planning which should include:

- In the first instance, adopting a catchment-based approach to minesite water management. This will identify current and potential water management issues in the catchment containing the mine leases, and will assess how mining may exacerbate or ameliorate problems. This approach will ensure minesite water management takes account of catchment issues as well as lease-area ones

Appendix 7 Ctd.

- Incorporating public consultations (with regulators and stakeholders) to ensure their concerns are identified and addressed
- Planning to address water management issues connected with the development, operation and decommissioning phases of mining
- A risk management approach to how changing levels of flood, drought and water quality risks should be addressed
- A risk management approach to identify and deal with operational risks that generate potentially adverse water management consequences
- Identifying and assessing a full range of management measures and options
- Identifying and using appropriate performance indicators to assess effectiveness of the MWMP

Of particular importance is 'Community Expectations'. Best practice principles dictate that minesite water management must strive to ensure that during the course of mining, downstream water users and riparian habitats (and their environmental values) are not adversely affected by the impact of mining operations. Again, at the end of mining, appropriate minesite water management measures should be implemented to sustainably protect water quality and riparian habitats downstream.

An important best practice environmental goal of minesite water management is to protect (and if possible enhance) the environmental values (including ecosystem protection; recreation and aesthetics; drinking and industrial use) of rivers and streams affected by mining operations. This entails monitoring of stream flow and quality.

To accurately monitor streamflow, mine management should site streamflow stations so that they co-ordinate with rainfall and water quality monitoring sites. In particular, streamflow stations should facilitate calibrating any numerical hydrologic or hydraulic models proposed in the minesite water management plan. At least, one 'key' streamgauging station should be established (i.e., a site where a current metre can gauge streamflows to determine a reliable rating curve). The selection of such sites should be done by experienced hydrologists. If appropriate, consideration should be given to adopting an existing station or reactivating a decommissioned station as part of the streamgauging network

For effective water quality monitoring, monitoring sites are needed at mining lease entry and exit points on all major water bodies at risk from mining operations. This allows any change in the quality of streamflows entering and leaving the lease area to be unambiguously defined. Water quality should also be monitored in at least one control catchment not affected by mining. This provides an indication of the 'natural' variation in water quality over the course of mining. Event-based sampling programmes are needed – runoff events, for instance, are far more significant than baseline flows for pollutant loads delivered to downstream receiving waters.

A water quality management sub-plan is an essential part of a minesite water management plan and must include:

- separating surface runoff from 'clean' areas of the minesite as effectively as possible from 'dirty' area runoff and from 'dirty' water bodies

Appendix 7 Ctd.

- controlling (at source if possible) pollutants or water contaminants
- designing and implementing appropriate water quality monitoring programmes to measure baseline and operational water quality parameters and appropriate parameters in emergencies

Despite the best plans, emergencies are likely to arise in operating a minesite water management system, e.g., pipelines may rapture, 'dirty' water storages may spill in an uncontrolled fashion. It is essential that such emergencies are investigated comprehensively to identify the magnitude, impact and circumstances that caused them. Best practice principles for emergency monitoring should ensure that:

- each mine has an emergency monitoring plan, i.e. a plan identifying possible emergencies (using risk management) and appropriate management strategies
- the emergency monitoring plan addresses the volume, discharge rate and quality of water that 'escaped' and its impact on downstream receiving water bodies
- the emergency monitoring plan addresses the possibility of alerting downstream landholders and water users of what has happened and its likely adverse impact on water supply and / or quality

Of particular importance in flood-prone areas is the issue of flood risk and hazard management. Best practice principles for managing flood risk and flood hazard on such minesites should include evaluating of flood behaviour, peak flood discharges and peak flood levels across the minesite for a range of flood events, by experienced hydrologists. Best practice minesite water management also calls for identification of the elements that the various flood events may affect and the nature of potential hazards to these elements, followed by the development of a comprehensive and appropriate risk management plan for the identified potential flood hazards.

APPENDIX 8

BPEM in Mining: Noise, Vibration & Blast Control (Environment Australia, 1998b)

The following BPEM measures can be taken, for effective control of minesite noise, vibration and blast:

i. *Noise, Vibration and Airblast Impact Assessment / Design of Control Measures*

The first stage of the environmental management process is to conduct an environmental impact assessment. The project proposal is examined in detail and all potential sources of noise, vibration and airblast impacts are identified. Another stage in the assessment procedure is to determine the level and character of the existing noise environment. Results obtained are used to establish noise level design goals. Any likely changes in noise level and character caused by the project can then be compared to these design goals and thus managed. In setting design criteria for noise emissions from continuous operations, there are two main objectives:

- That noise from a development does not greatly intrude above the prevailing background noise level
- That the noise level from an activity does not exceed the limit appropriate for the particular locality, land use and environmental values of the surroundings

Ensuring background noise levels are generally not exceeded by more than 5 dBA should limit the potential offensiveness of noise from a specific source. Predicting noise levels from blasting and other activities using environmental noise modelling software usually does this. SoundPLAN, developed in Germany by Braunstein & Berndt GmbH is one such software. This software is written to implement various internationally recognised noise prediction codes. The project model developed using SoundPLAN generates noise emission levels and noise contours taking into account factors such as source sound power levels and location, distance attenuation, ground adsorption, air adsorption, acoustical shielding and meteorology (including wind effect).

Costed mitigation measures (incorporated in a Noise, Vibration and Airblast Management [NVAM] Plan) should be undertaken where assessments of predicted levels of noise and vibration show the recommended design goals will be exceeded as a result of the mining project. The NVAM plan should be developed during the mine-planning phase. Its major purpose is to demonstrate the company's commitment to achieving environmental goals by clearly establishing the existing environmental noise and structural conditions, stating the design objectives, statutory requirements, control measures, emission monitoring and reporting programme. The plan also establishes procedures for handling of any exceedances and complaints and community liaison procedures. In order of decreasing effectiveness, measures that can be used to control noise levels include:

- Selecting low noise plant and equipment incorporating available noise control kits – this should be among one of the first measures chosen to minimise noise impact. For example, exhaust and radiator silencers on large earthmoving plant will generally result in a 5 dBA noise reduction

- Adding attenuations to mine ventilation fans – as with silenced plant items, this should be one of the first management options to ensure that fan noise levels will be reduced by a predetermined margin and emissions will not exceed acceptable limits
- Providing acoustical enclosures and acoustical treatment of process buildings – a reduction in the order of 10 dBA can be expected from a lightweight sheet metal enclosure. Ventilation openings should be oriented away from noise-sensitive receivers
- Provision of sound walls and acoustical screening – this option is generally effective when plant is operating at ground level in close proximity to the bund wall
- Incorporating optimum buffer zones and setback distances – this is only of use where large distances are involved. In general, doubling the distance between the source and receiver will result in a 6 dBA reduction in noise level

ii. *Control Measures for Vibrations*

Blast design can be altered to result in reduced levels of ground vibration by:

- Reducing the maximum instantaneous charge (MIC) by using delays and reduced hole diameter – at a given distance, reducing the MIC will generally result in lower levels of vibration

Appendix 8 Ctd.

- Changing the burden and spacing by (i), altering the drilling pattern and / or (ii), altering the hole inclination. The optimum use of explosives in blasting occurs when the available energy is efficiently used in fragmenting and moving the rock. When the hole inclination (relative to the force angle) is decreased or the burden and / or opening are increased, explosive energy cannot fully fracture the rock and the energy instead dissipates through the ground in the form of vibration
- Exercising strict control over spacing and orienting of all blast drill holes: Greater than optimum blasthole opening and orientation results in a greater degree of confinement and higher levels of ground vibration (as mentioned above)
- Using the minimum practicable sub-drilling which gives satisfactory toe conditions: While less than optimum sub-drill in blastholes results in 'toes' being left after the blast (i.e., rock remains intact above the level of the previous bench floor), too great a sub-drill will result in higher levels of ground vibration due to confinement of the explosives
- Investigating alternative rockbreaking techniques: Hydraulic rockbreakers and digging and ripping of product and overburden can (where feasible) ameliorate excessive levels of vibration caused by blasting
- Establishing times of blasting to suit local conditions: Least disruption and concern is caused by blasting when firing times are scheduled to coincide with periods of high activity rather than when people are sitting and relaxing in their homes

iii. *Control Measures for Airblast*

To reduce airblast the following measures can be investigated and implemented where found to be effective:

- Reduce the MIC – at a given distance, reducing the MIC will generally result in lower levels of airblast
- Ensure stemming depth and type is adequate: Excessive levels of airblast are often associated with stemming ejection, which commonly occurs when drill cuttings are substituted for stemming aggregates. Optimising the depth of stemming should also maximise energy release into the overburden or ore body
- Eliminate exposed detonating cord and secondary blasting: In the event that an explosive detonating cord is used to detonate the blastholes, it should be covered with a suitable aggregate material. However, the potential for initiation-related airblast emissions can be minimised with the use of NONEL (non electrical) initiation systems
- Restrict blasts to favourable weather conditions: The propagation of airblast is subject to meteorological conditions including refractions by wind and temperature gradients. Wherever possible, blasting should be confined to between 0900 hours and 1700 hours to minimise the noise-enhancing effects of temperature inversions
- Orient blast faces away from potentially sensitive receivers: Subsonic airblast noise levels are often associated with face heave which generally propagates noise emissions from the blast face. Orientating the blast face away from receiver locations can therefore reduce airblast levels

- Use a hole spacing and burden which will ensure that explosive force is just sufficient to break the ore of the required size: Excessive use of explosives may result in the release of energy into the atmosphere in the form of acoustic emissions
- Take particular care where the face is already broken and consider deck loading where appropriate to avoid broken ground or cavities in the face: High airblast levels may arise from face 'blowout' which commonly results from existing fractures or uneven face burden
- Conduct blasting at a set time, or implement a pre-warning signal for nearby receivers: The preferred blasting method is to initiate the shot at a predetermined time which is well known to all potential receivers, while maintaining appropriate safety procedures

In addition to the measures above, the mining company should develop a 'Monitoring and Audit Programme'. This will help the company to maintain a continuous, up-to-date record of the environmental noise and blast emissions throughout the life of the mining project. The records enable the company or any other interested party, such as a statutory authority, to audit the project operations to ensure all relevant approval and licensing conditions are achieved. The audit programme must also address procedures covering non-compliance with consent limits or failure to meet environmental quality objectives. These procedures should be outlined in the NVAM plan and include identification of non-compliance and the planning and carrying of such corrective action as may be necessary.

APPENDIX 9

BPEM in Mining: Cyanide Management (Environment Australia, 1998c)

Best practice minesite cyanide management should include:

- establishing a cyanide management strategy as part of the mine's environmental management programme
- implementing initial and refresher cyanide training for managers, workers and contractors
- establishing well-defined responsibilities for individuals with clear chains of command and effective lines of communication within the workforce
- instituting safe procedures for cyanide handling – governing transport, storage, containment, use and disposal
- integrating the mine's cyanide and water management plans
- identifying and implementing appropriate options for reusing, recycling and disposing of residual cyanide from plant operations
- conducting regular cyanide audits and revising cyanide management procedures where appropriate
- developing a cyanide occupational and natural environment monitoring programme, and supporting this with a sound sampling, analysis and reporting protocol
- establishing carefully considered and regularly practised emergency procedures

BPEM means using cyanide responsibly to minimise the chance that workers or the environment will be harmed. This includes correctly managing transport, storage, handling and emergency procedures, and personal hygiene, and monitoring the working environment. It also requires well-trained and properly equipped personnel who are aware of current treatment methods for cyanide poisoning and know the principles of how cyanide acts on humans and animals. Important principles in managing cyanide effects on the environment are to:

- use the minimum effective amounts of cyanide required to recover metals
- dispose of cyanide in a way that eliminates or minimises environmental impacts
- monitor all operations, discharges and the environment to detect and deal with any escape of cyanide and subsequent impacts of its release

Best practice cyanide management should include appropriate controls during the storage and handling of the chemical as follows:

i. *Storage*

How cyanide is stored at the minesite depends on the form of cyanide. Holding facilities and compounds should be designed and maintained with the following in mind:

- Provide adequate ventilation to disperse any build-up of hydrogen cyanide gas
- Minimise the possibility of contact with water (appropriate measures for storage of solid sodium cyanide include provision of roofing, ensuring adequate drainage and storage above ground level or on an impervious surface)

Appendix 9 Ctd.

- Avoid potential contamination of water bodies by locating storage in bunded areas well away from natural drainage channels
- Store cyanide separately from corrosive, acidic and explosive materials
- Fence and lock the storage area to prevent accidental entry or access by unauthorised individuals (post clear warning signs)
- As fire is a potentially serious problem, locate and build facilities with this in mind. It may also be desirable to periodically remove vegetation from around storage facilities. 'HAZCHEM' code 4X warning signs are needed for identification by fire-fighters
- Adequate containment facilities and bunding of liquid and solid cyanide containers are necessary to minimise the effects of accidental spillage

ii. *Handling*

Best practice means not only adopting measures that minimise the likelihood of cyanide losses during operations but also ones that limit the effects of any loss. Cyanide handling must take into account the occupational exposure standard or Threshold Limit Value (TLV), which is 5 mg / m^3 for sodium cyanide powder and 10 ppm for hydrogen cyanide gas. Operators undertaking hazardous procedures involving cyanide (including opening storage containers; dissolving sodium cyanide pellets; and cleaning up cyanide spillages) should wear appropriate protective clothing and work in pairs with one acting as a 'sentry'. The role of a sentry needs to be carefully defined and followed. As a passive observer of the handling process, the sentry should participate in the process only in an emergency.

Most of the cyanide residue from ore processing activities ends up in the tailings ponds. In the ponds, in addition to natural degradation, the levels of cyanide can be reduced through: enhanced natural degradation processes; chemical, physical or biological methods; and recovery or recycling

a. *Enhancing Natural Losses*

Some relatively simple procedures can effectively increase the speed of natural degradation. For example, a shallow pond with a large surface area provides greater contact with atmospheric CO_2 which lowers the pH thus increasing the rate of conversion of CN to HCN and volatilisation. Aeration and mixing have a similar effect.

b. *Chemical, Physical and Biological Intervention*

Residual cyanide can be detoxified using the Degussa peroxide process. Put simply, hydrogen peroxide oxidises free and WAD (Weak Acid Dissociable) cyanides to cyanate (CNO^-), which is further hydrolysed to biodegradable ammonia and carbonate. Metals such as copper, zinc and cadmium complexed with cyanide are precipitated as hydroxides and iron cyanide complexes. These are then removed by a further treatment step that precipitates the iron cyanide complex by combining it with copper ions. The most cost-effective way to partially detoxify cyanide in tailings slurries is to use peroxymonosulphuric acid (Caro's acid) which can be generated safely on-site from hydrogen peroxide and sulphuric acid. Cyanide is converted to the less toxic cyanate.

c. *Recovery or Recycling*

When residual cyanide occurs as free and WAD cyanide, it may be recovered using various non-oxidative processes such as the AVR (Acidification-Volatilisation- Absorption) and CYANISORB®. Both processes rely on reducing pH to release HCN. AVR uses shallow aeration basins and high-pressure air blowers to recover free cyanide and some metal-cyanide complexes.

APPENDIX 10

BPEM in Mining: Tailings Containment (Environment Australia, 1995d)

The development of best processing technology, the physical design of the tailings structure, and the operation of the facility should all minimise any long term environmental impacts associated with mine tailings. By BPEM, many potential short and long term environmental problems can be avoided. Tailings management needs to cover a broad spectrum of activities. Issues that need to be considered in establishing BPEM in tailings containment should include:

i. *Meteorology*

Various aspects of the operation's water balance should be based on a thorough understanding of the meteorological conditions of the local area. Information that needs to be gathered includes:

- rainfall data – monthly averages for various return periods (example, 1:10, 1:50, or 1:100)
- rainfall intensity / duration
- characteristics of evaporation, humidity, temperature, wind strength / direction and knowledge of past or infrequent events (e.g. floods)

ii. *Topography and Mapping*

The topography of the long term construction and buffer areas to a distance of around 1 km from the boundaries of the future storage areas should be examined.

Appendix 10 Ctd.

This information will allow the potential social and environmental impacts of the proposed facility to be assessed in the very early stages of mine planning. The information should include: surface contours at 1 m intervals; drainage patterns (streams, springs, lakes / wetlands); land boundaries; roads and services; dwellings and other structures; cultural or heritage sites; and current land use.

iii. *Surface and Ground Water*

If the tailings storage area is to be sited in an area close to rivers or areas which could be subject to flooding, the potential impact of low frequency storm events needs to be considered. Again, an understanding of the general hydrogeology of the site will assist in the evaluation of the potential impact of the tailings storage on the ground water. Information required includes:

- flows of natural water courses
- flood records and possible flood plain identification
- background water quality
- upstream and downstream water use including environmental flows to maintain habitats for flora and fauna
- hydrogeology of the site (depth to water, flow directions, flow velocity)
- presence of preferred flow paths
- zone of groundwater discharge

Appendix 10 Ctd.

Tailings storage facilities need to be designed and operated to accommodate site-specific constraints. Each situation is different and there is no simple means of ranking factors such as tailings and site-selection characteristics, tailings dam construction and operational techniques to give a 'best' answer for tailings containment. The overriding approach aims to avoid both long and short term environmental problems and achieve the best environmental results. In the Western Australian Goldfields for instance, the upstream construction method – which is best suited to hard rock mining which produces silt-sand tailings – is the most commonly used tailings dam building technique.

One important aspect of the mine tailings management is monitoring. Because a tailings-storage facility has a life of its own, inspections must be part of the daily routine of operational staff, ideally as often as every shift.

APPENDIX 11

BPEM in Mining: Management of Sulphidic Mine Waste & Acid Drainage

(Environment Australia, 1997)

Best Practice environmental management principles for minimising sulphidic mine waste and acid drainage include early recognition of sulphide oxidation potential and incorporation of prevention strategies into the various stages of mine planning, design, operation and closure. The earliest opportunity to identify the potential for acid drainage at a specific site is during the exploration stage when drilling is occurring to 'prove up' an ore body. Drill core material can be used for geochemical testing and mineralogical examination utilising microscopic examination and X-ray diffraction analysis to characterise sulphide and carbonate species. Sampling for prediction of acid drainage should be ongoing and may include drill cuttings or rock chip sampling from outcropping rock units or active mining and development faces. Hence, the project geologist has a critical role to play in the initial identification and assessment of acid drainage potential. Relevant information should be logged and recorded from drill core, and development waste and ore zone core samples retained for further testing. This information can be integrated with the geological model for the mineral deposit and form the basis of initial mine planning strategies.

BPEM for sulphidic mine wastes requires a risk management approach. While the primary focus is to prevent acid generation, there is a hierarchy of appropriate management strategies as follows:

Appendix 11 Ctd.

- Minimise oxidation rate and isolate higher risk materials from exposure
- Minimise potential for transport of oxidation products from source to receiving environment
- Contain and treat acid drainage to minimise risk of significant off-site impacts

Environmental management of acid drainage requires an understanding of the geochemistry of the ore body for use in predictive tools. Prediction can be achieved through static and kinetic testing of mine rock, which can provide information on likely metal / sulphate (oxidation products) loads and concentrations. This information should be incorporated into the mine geological model and mining schedule to provide for the necessary selective handling and disposal of higher risk materials, subject to site-specific considerations. Identifying the geochemical nature of waste samples, for instance, is necessary to assess their potential for sulphide oxidation leading to acid generation.

The principles of preventing and remediating acid drainage involve a combination of mechanisms including:

- exclusion of oxygen from sulphidic mine wastes
- control of water flux within wastes and management of site hydrology to minimise potential for transport of oxidation products (sulphate, metals, etc.)
- neutralisation of acid drainage with alkaline materials
- monitoring to characterise wastes and determine the effectiveness of remediation measures

The most cost-effective management strategy for sulphide oxidation is integration of oxidation and hydrological controls throughout mining operations, from mine planning to mine closure, and working in a co-ordinated manner to minimise the risk of acid drainage developing. Basically, control strategies require exclusion of one or more of the inputs that result in oxidation, i.e., sulphide minerals, oxygen or water. Where acid drainage generation cannot be eliminated, it may be treated or its release regulated to a rate that will not affect the receiving environment. Minimising acid drainage requires control of:

- Sulphide oxidation and acid generation rates by regulating oxygen, water, bacteria or other limiting factors, for example, alkalinity – the use of soil covers (waste rock, clay subsoils or oxide wastes and synthetic membranes, e.g., geotextile fabrics) can reduce the diffusion rate of oxygen, as well as the water flux / transport, in the sulphide material
- Control of alkalinity and acidity balance so oxidation products and other soluble constituents are precipitated and immobilised within the material

Once AMD has occurred, it can be treated by one or more treatment processes including alkaline neutralisation, use of passive anoxic limestone drains and wetland treatment systems.

APPENDIX 12

BPEM in Mining: Environmental Monitoring & Performance (Environment Australia, 1995e; 2000)

The following list provides a framework for the design of BPEM minesite monitoring programmes:

- Identify the scope of the monitoring and list the sub-programmes corresponding to each environmental issue
- Define the objectives for each monitoring sub-programme
- Specify how information collected will be used in the decision-making process
- Define the spatial and pathway boundaries for the work, and select map or plan scales and sites for observation, measurement and sampling
- Based on appropriate characterisation studies, select the key indicators for direct measurement, observation or sampling
- Define how the data will be analysed and interpreted, and how it will be presented in the monitoring report
- Define the precision and accuracy required in the data
- Consider compatibility of the data to be collected with historical data and with contemporary related data
- Set minimum requirements for monitoring air, water, discharges and biological systems among others

The above principles can be applied to the monitoring of key aspects of the environment such as water, land, flora and fauna (biological monitoring), air and noise, processes and wastes, and, people and communities (including heritage values) as described below:

i. *Water Monitoring*

Water is potentially a major transport medium for contaminants. Contaminated excess waters are managed by evaporation, chemical or physical treatment, land application, wetland filters or in-stream dilution. Where excess waters must be disposed of to the downstream or adjacent environment, more detailed attention to water chemistry, aquatic biology and hydrology is required. A water monitoring programme needs to address the following requirements:

- Determine key water quality indicators – such indicators must be easy to measure and unambiguously related to environmental change in the identified environmental value. Examples of key environmental indicators for a mine experiencing acid mine drainage would be pH, Electrical Conductivity (EC), SO_4^{2-} and various trace metals
- Identify catchments and define location of sampling sites for surface and ground water monnitoring
- Specify temporal sampling frequency, e.g., whether continuous or at monthly intervals depending on hydrological variability
- Use standard sample collection and preservation techniques
- Choose appropriate chemical analytical methods to achieve maximum sensitivity and reliability of results

- Use appropriate quality control procedures for checking reliability of test results (i.e., calibration, duplicate sampling, external analysis, standard reference materials and maintenance of equipment)
- Evaluate and review test results and adjust monitoring programme and / or practices

ii. *Land Monitoring*

This monitoring relates directly to the land management components of an Environmental Management Plan (EMP), i.e., minimisation of disturbance, weed control, optimisation of topsoil / subsoil use, fire management, erosion control (earthworks and revegetation) and protection of specific landscape features / aesthetic features. A land monitoring programme needs to address the following requirements:

- Identify areas to be monitored for each of the key issues
- Specify appropriate method and frequency of monitoring for each aspect, e.g., map weeds, maintain photographic records of erosion and sedimentation, check topsoil stockpiles
- Evaluate and review results / observations and adjust monitoring programme and / or practices

Appendix 12 Ctd.

iii. *Biological Monitoring*

Biological aspects of the environment usually monitored include endangered species of flora and fauna, feral animals, mosquito / health risk vectors, and soil / plant pathogens. Specific indicator organisms may also be used to measure potential impacts on other biological groups. Due to the complexity and dynamics of biological systems, baseline studies over several seasons / years are necessary to define the key indicators that will be used in a monitoring programme. It is necessary to commence monitoring just before the construction phase, and to continue throughout the duration of mining and for some time after decommissioning and rehabilitation. A biological monitoring programme needs to address the following requirements:

- Define community and species dynamics
- Select appropriate indicators for direct toxicity or bioaccumulation measurements
- Consider variations due to space and time (cost, time and uncertainty of biological measurements must be considered)
- Direct impact on biological communities
- Use widely accepted and standardised methods where possible
- Collect adequate data for appropriate statistical analysis with special attention on short term effects, local and regional effects, individual species and broad community impacts
- Evaluate and review test results and adjust monitoring programme and / or practices

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iv. *Air and Noise Monitoring*

Dust, gases, blasting (vibration) and noise are key issues to be addressed in the EMP and subsequent monitoring programmes. An air and noise monitoring programme needs to address the following requirements:

- Define location of monitoring sites – it is vital that selected locations are appropriate for achieving aims, having regard to point sources, prevailing winds and potential impact sites
- Specify temporal frequency – may be continuous or timed according to specific activities, or during short specific periods for assessment of ground vibration associated with blasting monitoring
- Select the most suitable monitoring equipment to meet set objectives
- Establish appropriate quality control procedures to ensure reliability of results (i.e., calibration with standard source materials)
- Establish appropriate equipment maintenance programme – all atmospheric and vibration monitoring equipment must be maintained to the appropriate government and industry standards and backup provided
- Ensure information provided to the user is relevant to the aim of the programme and that data are presented on time and in an easily useable format – in most situations data need to be analysed automatically for which alarm systems may be incorporated
- Evaluate and review test results and adjust monitoring and / or practices

Appendix 12 Ctd.

v. *Process and Waste Monitoring*

Waste materials, waste rock, tailings, process chemicals, ore and mill products are potential sources of chemical contamination of water, soil and air. Management of water associated with these sources is a key to protection of the environment. A particularly serious issue is the heavy metal leaching associated with the generation of acid mine drainage. Waste rock containing sulphide minerals requires attentive management to control acid generation to oxidation processes. Process and waste monitoring needs to address the following:

- Establish a water and air quality monitoring programme in relation to the various wastes
- Check placement and management of the different wastes, ore and process chemicals (e.g., sulphidic waste rock being placed according to acid generation potential (AGP) classification
- Check engineering quality and stability of containment structures and covers on tailings dams and waste rock dumps – including effectiveness of compaction and erosion control measures to minimise acid generation and leachate production
- Inspect hazardous storage facilities and work practices, operational conditions and maintenance procedures
- Evaluate and review test results and adjust monitoring programme and / or practices

vi. *People & Community Monitoring*

Environmental issues that need to be addressed in this monitoring sub-programme include the potential impacts on people and culture / heritage within close proximity to the mining operation. These issues require very specialised techniques and, for example, may include studies of foodstuffs (if local bush food is a predominant component of the diet of people living in the area – e.g., critical group studies), protection of cultural or heritage values (e.g., sacred sites or historical features) and air / water quality as it relates directly to people). The People and Community Monitoring Programme should also:

- Identify critical groups of people and special areas potentially affected by mining operations
- Define location of monitoring sites for water or atmospheric monitoring
- Define access limitations for protection of cultural / heritage sites and check regularly for employee knowledge of restrictions
- Define diet components for food contaminant uptake studies
- Use standard sample collection and preservation techniques
- Choose appropriate analytical methods to achieve maximum sensitivity and reliability of test results
- Use photographic and mapping techniques to monitor protection of / damage to special areas
- Use appropriate quality control procedures for checking reliability of test results
- Define appropriate liaison techniques for consultation with relevant groups of people

- Evaluate and review test results / observations and adjust monitoring programme and / or practices

Efficient techniques are essential for a successful minesite monitoring programme. For instance, some Geographical Information System (GIS) software (example, EarthMap and Mapinfo) are very effective for mine environmental monitoring and other minesite operations due to their efficiency and cost-effectiveness. A typical environmental monitoring programme at a mine may generate hundreds and even thousands of discrete results or data points each year. This means that over the average life of a mine, tens of thousands of results must be stored and analysed in order to assess the environmental performance of the operation. This huge task can be reduced by the use of GIS applications for data storage and management. The main benefit of GIS, as against just spreadsheet and database systems for the management of environmental data, is that it enables non-spatial data to be linked to spatial data. EarthMap for instance adds environmental functionality ('ecosystem function analysis' [EFA]) to MapInfo, allowing environmental professionals to store, analyse and present data (on existing and final surface profiles, mining and waste volume changes, progressive and final revegetation requirements and the results of any environmental or geotechnical investigations among others) quickly and easily. Many of the difficulties of spreadsheet and database systems are overcome when used with a GIS system with environmental functionality such as EarthMap. Overall, this will lead to more informed and hence better environmental decision-making at a mine site. While the time required for the establishment of a GIS may be greater than for spreadsheet and database systems, the spatial capability of GIS will allow more efficient analysis of data, and may lead to overall reduction in time and cost.

APPENDIX 13

BPEM in Mining: Rehabilitation & Revegetation (Environment Australia, 1995f)

The basic Best Practice principles of minesite rehabilitation / revegetation that should always be followed are as follows:

- Prepare a rehabilitation plan prior to the commencement of mining
- Agree on the long-term post-mining landuse objective for the area with the relevant government departments, local government councils and private landowners. The landuse must be compatible with the climate, soils, topography of the final landform, the land capability of the rehabilitated area, and the degree of management available after rehabilitation
- Progressively rehabilitate the site where possible, so that the rate of rehabilitation is similar to the rate of mining
- Prevent the introduction of noxious weeds and pests
- Minimise the area cleared for mining and associated facilities to that absolutely necessary for the safe operation of the mine. Where possible, a use should be found for the cleared vegetation (it can often be used during rehabilitation as a source of seed, as a mulch to protect soil from erosion or as habitat for fauna)
- Reshape the land disturbed by mining so that it is stable, adequately drained and suitable for the desired long-term landuse
- Minimise the long-term visual impacts by creating landforms that are compatible with the surrounding landscape
- Reinstate natural drainage patterns disrupted by mining wherever possible

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- Minimise the potential for erosion by wind and water both during and following mining
- Remove or control residual hazardous materials – identify any potentially toxic overburden or exposed strata and manage them so as to prevent environmental damage
- Characterise the topsoil and retain it for use in rehabilitation – it is preferable to reuse the topsoil immediately rather than storing it in stockpiles. Only discard it if it is physically or chemically undesirable, or if it contains high levels of weed seeds or plant pathogens
- Consider spreading the cleared vegetation on disturbed areas
- Deep-rip compacted surfaces to encourage infiltration
- Ensure that the surface one or two metres of soil is capable of supporting plant growth
- Wherever possible, the topsoil should be immediately replaced on an area where the landform reconstruction is complete – direct return has several advantages compared with placing the topsoil in stockpiles and storing it for later rehabilitation. If the topsoil must be stockpiled then it should be for as short a time as possible
- Revegetate the area with plant species consistent with the post-mining land use
- Make the area safe
- Remove all facilities and equipment from the site
- Monitor and manage rehabilitated areas until the vegetation is self-sustaining and meets the requirements of the landowner or land manager, or until their management can be integrated into the management of the surrounding area

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Other issues that need to be considered in mine site rehabilitation and revegetation programmes are discussed below.

i. *Alternative Substrates / Soil Amendments*

If topsoil is unavailable, the cost of transporting is prohibitive, or the topsoil contains such high levels of weed seed or plant pathogens that it is unsuitable for rehabilitation, then subsoil, overburden, waste rock or similar materials must be used as a substrate for revegetation. These materials will generally require techniques to increase their organic matter content and nutrient status. Their physical characteristics may require amelioration and their pH may need to be adjusted. The physical and chemical properties of the proposed substrates should be thoroughly investigated prior to their use in rehabilitation. The following techniques can be applied for the improvement of the soil's ability to support plant growth in the long term:

- Application of organic matter such as animal manures, sewage sludge or other wastes
- Chemical amendments such as gypsum (to improve the structure and reduce the pH of highly alkaline substrates), lime (to raise the pH of acid substrates) and inorganic fertilisers
- Soil conditioners – many proprietary soil conditioners, such as polyvinyl alcohol polymers, are available which may have application in certain situations. Trial areas should be treated to assess their value before large areas are treated
- Growing green manure crops which can be incorporated into the substrate

- Establishing nitrogen fixing species such as legumes to increase the organic mater and nitrogen content of the substrate
- Applying mulch

ii. *Landform Design and Reconstruction*

The re-shaping and grading of a site is an essential aspect of rehabilitation. The need for extensive re-shaping of spoil piles can sometimes be minimised by good mine planning and management. The final landform must be hydrologically compatible with the surrounding area. Slopes must be stable and will be less obtrusive if they have a similar gradient to natural slopes in the area, although this is not possible in many cases. Other factors that need to be considered are:

- Stability – the maximum angle and length of slope that will be stable depends on site-specific variables such as spoil and topsoil characteristics, and rainfall intensity. The erosion potential of the different materials on site needs to be assessed and a geotechnical investigation may be required
- Drainage density – the drainage density of surrounding areas will provide a guide; an increase in drainage density may be required if there have been an increase in the gradient of slopes and changes in the nature of the surface materials

iii. *Erosion Control*

Measures to protect the soil from water erosion should be carried out on a catchment basis. Drainage from external catchments must be controlled by diversion channels or holding structures such as banks, drains and dams. Water leaving the site or diverted around the site must also be controlled. It is necessary to discharge this water so that it does not cause erosion or carry sediment downstream. Sediment dams are the most common means of controlling sediment levels in runoff. On disturbed areas control of water erosion is achieved by:

- slowing the water flow across the soil surface – by encouraging infiltration and building drainage control structures to channel water off the site. Infiltration can be encouraged by ripping and cultivating on contour and constructing contour banks
- reducing the impact of raindrops on the soil surface using mulches
- maintaining the soil in an erosion-resistant condition – soils are more resistant to erosion when they are kept in a cloddy condition

iv. *Revegetation*

When attempting to restore a native ecosystem, the initial revegetation effort is unlikely to produce a vegetation identical to the original. The initial revegetation efforts should however establish the building blocks for a self-sustaining system, so that successional processes lead to the desired vegetation complex. The best time to establish vegetation is determined by the seasonal distribution and reliability of rainfall. All the preparatory works must be completed before the time when seeds are most likely to experience the conditions they need to germinate and survive, i.e. reliable rainfall and suitable temperatures. The species selected for revegetation will depend on the future landuse of the area, soil conditions and climate. If the objective is to restore the native vegetation and fauna then the species are pre-determined. Some indigenous species may not thrive in areas where soil conditions are substantially different after mining. If this is the case, and the objective is to re-establish vegetation that fulfils the functions of the original native vegetation, then some species from outside the mining area will have to be introduced. Species which have similar growth forms to the original vegetation, and thrive in areas with comparable soil types, drainage status, aspect and climate to the rehabilitated area, are the most appropriate.

Where the future landuse is agriculture, then the species selected should be those that are commonly used for pastures or crops in areas with a comparable climate on soils of similar texture, drainage status, pH and fertility. Suitable legumes should always be considered for their ability to improve soil fertility. Cover crops can be considered where a quick cover for erosion control is required. When establishing native plants with a cover crop, a compromise must be reached between the density of the cover crop needed to provide erosion control, and the tendency of the cover crop to suppress or smother the native species.

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v. *Fauna*

Encouraging the native fauna to return to areas cleared for mining is a fundamental part of any rehabilitation programme that aims to restore a natural ecosystem. Some invertebrate species will be introduced if fresh topsoil is placed on the area, but most fauna species will need to recolonise from surrounding areas. The rate of recolonisation by fauna is influenced by a range of factors including the size of the rehabilitated area, the fauna populations in surrounding areas and the success of the revegetation programme. Many fauna groups will quickly colonise any areas which contain the resources they require such as food, shelter and breeding sites. In many cases, the main objective of a fauna return strategy should be the re-establishment of the native vegetation. If this is successful, then the fauna should colonise from surrounding areas. Difficulties in re-establishment will occur when fauna population levels are low in surrounding areas or a species is locally extinct. In these cases a captive breeding and release programme, or re-introduction programme from another area, may be appropriate. However, the reasons why the populations are low need to be understood and controlled so that the introduced animals do not succumb to the same pressures which reduced the original populations.

APPENDIX 14

Summaries: AGC Water Quality Monitoring Data: 1998 – 1999

Table A14.1: AGC (Obuasi) Water Quality Monitoring Results – pH (pH Units)

	*MS1		*MS2		*MS3		**MS4		*MS5		*MS6		**MS7		*TNS	TNS < / > *EPAMPL	% (TNS) < / > EPAMPL
Month / Year	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late			
Jan '98	6.9	7.1	7.5	7.5	7.2	7.2	7.0	7.4	7.2		7.2	7.1	7.1	7.2	14	Nil	Nil
Feb '98	7.6	7.8	7.4	7.6	7.4	7.5	7.3	7.5	6.8		6.7	6.9	6.8	6.8	14	Nil	Nil
Mar '98	7.5	7.8	7.1	7.3	7.3	7.4	7.2	7.4	6.7		6.8	6.8	7.2	6.7	14	Nil	Nil
Apr '98	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-
May '98	7.9	7.3	7.6	7.2	7.4	7.1	7.7	7.3	7.1		6.9	7.0	7.1	6.8	14	Nil	Nil
Jun '98	7.5	8.3	7.5	7.2	7.4	7.9	7.2	7.6	6.9	8.1	6.7	7.5	6.9	7.2	14	Nil	Nil
Jul '98	7.5	7.5	7.9	7.8	7.7	7.9	7.1	7.5	7.8	8.0	7.0	7.7	7.2	7.5	14	Nil	Nil
Aug '98	7.5	7.9	7.9	7.4	7.6	7.5	7.2	7.2	7.9	7.2	7.2	7.2	7.3	7.1	14	Nil	Nil
Sep '98	8.2	7.8	7.8	8.1	7.6	8.0	7.6	7.5	6.8	7.3	7.0	7.2	7.3	7.2	14	Nil	Nil
Oct '98	7.7	7.3	8.2	7.9	8.1	7.5	7.2	7.6	7.8	7.4	7.6	7.4	7.5	7.2	14	Nil	Nil
Nov '98	6.7	7.7	7.7	7.9	7.5	7.7	7.1	7.3	7.4	7.3	7.1	7.2	7.2	7.1	14	Nil	Nil
Dec '98	7.1	7.2	7.5	7.2	7.2	7.1	7.2	7.1	6.4	6.5	6.6	6.6	6.9	7.1	14	Nil	Nil
Jan '99	7.7	7.0	7.6	7.6	7.7	7.4	7.5	7.4	6.9	7.3	6.9	7.2	6.8	7.2	14	Nil	Nil
Feb '99	7.9	7.8	7.7	7.6	7.6	7.7	7.5	7.3	6.9	6.7	6.8	6.7	6.7	6.6	14	Nil	Nil
Mar '99	7.4	7.6	7.2	7.4	7.4	7.4	7.3	7.4	6.6	7.2	6.6	7.1	6.9	6.9	14	Nil	Nil
Apr '99	7.9	7.6	7.7	7.5	7.7	7.6	7.4	7.4	7.2	7.0	7.1	7.0	7.0	7.1	14	Nil	Nil
May '99	7.8	-	7.7	-	7.7	-	7.2	-	7.0	-	7.1	-	7.1	-	7	Nil	Nil
Jun '99	7.2	7.5	7.6	7.2	7.2	7.3	7.0	7.2	6.9	7.0	6.7	6.8	6.8	6.7	14	Nil	Nil
Jul '99	-	7.6	-	7.4	-	7.5	-	7.3	-	7.2	-	7.2	-	7.2	7	Nil	Nil
Aug '99	7.9	7.7	7.8	7.6	7.3	7.4	7.2	7.2	**5.7**	6.2	**5.6**	**5.8**	7.0	6.3	14	**3**	**21.4**
Sep '99	-	8.0	-	7.8	-	7.9	-	7.5	-	6.9	-	6.7	-	6.8	7	Nil	Nil
Oct '99	7.3	7.1	7.1	7.2	7.0	7.3	7.1	7.0	6.9	6.7	6.9	6.5	6.7	7.0	14	Nil	Nil
Nov '99	7.1	7.3	7.7	6.9	7.6	7.0	7.4	7.2	7.4	7.3	7.4	7.4	7.4	7.4	14	Nil	Nil
Dec '99	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Nil	Nil

- → No sampling carried out or results not available; Highlighted Values→Values above EPAMPL (6 – 9 pH Units)

*MS1 = Pompora Decant (Decant Water on the Tailings Dam near the Pompora Sulphide Treatment Plant)

*MS2 = Coffer Dam Upstream of the Kwabrafo River

*MS3 = Pompora Sump (Downstream of the Pompora Talings Dam)

**MS4 = Kwabrafo River at Amansan Clinic

*MS5 = Sansu Tailings Dam

*MS6 = Sansu Holding Pond (Settling Pond near the Sansu Tailings Dam)

**MS7 = River Nyam at Nyamebekyere

*TNS = Total Number of samples

*EPAMPL = Ghana EPA Maximum Permissible Limit

Summary of Key Environmental Isues (from Table A14.1):

For the two-year period of fortnightly water quality monitoring above, it was only in August 1999 that some (21.4 %) samples analysed had pH's above the EPAMPL. In all, only 3 out of the 287 samples analysed over the two-year period (1.04% samples) had pH values above the EPAMPL

Table A14.2: AGC (Obuasi) Water Quality Monitoring Results – Total Cyanide (mg l^{-1})

Month / Year	*MS1		*MS2		*MS3		**MS4		*MS5		*MS6		**MS7		*TNS	TNS > *EPAMPL	% (TNS) > EPAMPL
	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late			
Jan '98	**1.5**	**23**	0.4	0.36	0.9	1.0	0.3	0.3	**24.8**	**27.0**	**12.8**	**16.6**	**3.0**	**5.8**	14	8	57.1
Feb '98	**5.8**	**2.4**	**8.2**	**15.3**	**4.5**	**7.8**	0.1	0.4	**15.8**	**12.5**	**23.2**	**14.8**	**4.3**	**1.4**	14	12	85.7
Mar '98	**17.2**	**12.8**	**6.5**	**3.7**	**8.2**	**6.3**	**1.9**	**1.8**	**21.3**	**26.2**	**18.6**	**13.5**	**5.3**	**4.8**	14	14	100
Apr '98	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
May '98	**4.9**	**14.7**	**5.8**	**10.7**	**6.5**	**5.9**	**1.4**	0.9	**10.3**	**11.5**	**12.6**	**8.9**	**2.8**	**1.3**	14	13	92.8
Jun '98	**7.0**	**30.4**	<.01	**7.6**	**6.6**	**7.9**	<.01	**1.8**	**28.2**	**9.9**	**13.1**	**13.9**	**4.6**	0.1	14	11	78.6
Jul '98	**2.1**	**1.3**	**1.4**	0.15	**1.3**	0.21	0.4	<.01	**9.2**	**8.0**	**4.8**	**6.8**	<.01	0.9	14	8	57.1
Aug '98	0.5	1.7	0.1	3.4	0.2	**3.8**	<.01	**1.8**	**28.2**	**9.9**	**13.1**	**13.9**	**4.6**	0.1	14	7	50
Sep '98	**20.4**	**6.7**	**6.7**	**1.5**	**3.6**	**4.0**	0.1	0.9	**29.6**	**0.9**	**17.2**	**1.6**	0.1	0.1	14	10	71.4
Oct '98	**14.2**	**20.9**	**2.1**	**13.7**	**6.3**	**18.4**	0.7	0.8	**24.7**	**22.0**	**5.91**	0.9	0.6	0.4	14	9	64.3
Nov '98	**10.1**	**14.6**	0.4	**6.6**	**1.3**	**7.0**	<.01	0.8	**19.8**	**13.1**	**8.7**	**7.9**	<.01	<.01	14	9	64.3
Dec '98	**12.4**	**11.3**	**5.4**	**5.4**	**8.6**	**6.6**	0.5	<.01	**12.6**	**11.8**	**11.7**	**8.8**	0.3	0.4	14	10	71.4
Jan '99	**15.8**	**16.7**	**15.2**	**16.1**	**15.1**	**17.7**	0.9	**4.8**	**14.4**	**38.4**	**14.1**	**34.8**	**2.2**	**3.5**	14	13	92.8
Feb '99	**5.6**	**23.8**	**6.1**	**10.8**	**3.9**	**8.3**	0.01	0.4	**14.6**	**10.5**	**19.1**	**11.0**	**3.2**	0.9	14	11	78.6
Mar '99	**14.0**	**11.0**	**5.6**	**2.8**	**8.0**	**2.8**	**1.7**	**1.8**	**29.0**	**19.2**	**26.6**	**15.4**	**2.1**	0.6	14	13	92.8
Apr '99	**6.4**	**10.6**	**3.6**	**5.5**	**4.5**	**8.7**	<0.1	**1.4**	**16.0**	**18.8**	**14.9**	**17.6**	**1.1**	**1.5**	14	13	92.8
May '99	**4.2**	-	**3.9**	-	**3.2**	-	0.3	-	**2.7**	-	**4.2**	-	0.6	-	7	5	71.4
Jun '99	**1.4**	**9.0**	**1.6**	**8.0**	**1.8**	**8.7**	<.01	<.01	**15.6**	**14.6**	**14.0**	**13.6**	**2.8**	**2.6**	14	12	85.7
Jul '99	-	**28.5**	-	**17.0**	-	**24.0**	-	**6.7**	-	**17.8**	-	**15.8**	-	**6.4**	7	7	100
Aug '99	**14.9**	**16.9**	**6.6**	**14.2**	**12.2**	**18.4**	**1.6**	**4.7**	**20.0**	**15.2**	**19.3**	**21.4**	**1.8**	**2.3**	14	14	100
Sep '99	-	**24.2**	-	**15.6**	-	**22.0**	-	**7.8**	-	**15.6**	-	**14.0**	-	**2.8**	7	7	100
Oct '99	**24.0**	**9.8**	**16.7**	**6.0**	**3.5**	**4.3**	0.1	0.8	**22.4**	**30.4**	**24.0**	**34.4**	0.7	**1.5**	14	10	71.4
Nov '99	**4.8**	**2.4**	**2.3**	**3.5**	**2.4**	**4.5**	0.1	**2.0**	**28.0**	**24.0**	**20.7**	**22.0**	0.2	0.2	14	11	78.6
Dec '99	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Highlighted Values → Values above Ghana EPA Maximum Permissible Limit (1.0 mg l^{-1})

<u>**Appendix 14 Ctd.**</u>

Summary of Key Environmental Issues (from Table A14.2):

(i) With the exception of one month (August 1998), cyanide concentrations of more than half (>50%) of samples analysed each month exceeded the EPAMPL

(ii) For the two-year period of fortnightly cyanide monitoring, 227 out of the 287 samples analysed (79% of the samples) had cyanide concentrations above the EPAMPL

(iii) Cyanide concentrations of samples were particularly high in the dry months (January to April, and, October to December, with concentrations as high as 30 times the EPAMPL measured in some samples collected in October 1999

(iv) Of particular concern is the number of occasions when water samples from River Nyam (**MS7) [54% of samples collected from the river] had cyanide concentrations above the EPAMPL

(v) Even at the peak of the rains (June / July), cyanide concentrations of most samples analysed (including samples from Rivers Kwabrafo and Nyame) exceeded the EPAMPL

Table A14.3: AGC (Obuasi) Water Quality Monitoring Results – Total Arsenic (mg l^{-1})

Month / Year	*MS1		*MS2		*MS3		**MS4		*MS5		*MS6		**MS7		*TNS	TNS > *EPAMPL	% (TNS) > EPAMPL
	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late			
Jan '98	**20.5**	**35.7**	**17.0**	**14.3**	**22.5**	**20.2**	**3.8**	**9.8**	1.3	1.0	1.0	1.0	0.8	0.5	14	8	57.1
Feb '98	**19.4**	**89.6**	**36.7**	**48.8**	**39.2**	**60.5**	**15.3**	**6.8**	0.8	**3.4**	**5.6**	**3.7**	1.3	0.9	14	11	78.6
Mar '98	**32.8**	**47.3**	**29.2**	**31.8**	**25.7**	**36.4**	**9.8**	**11.3**	1.2	1.4	0.9	1.3	0.7	0.8	14	8	57.1
Apr '98	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
May '98	**33.6**	**31.9**	**26.3**	**29.7**	**28.4**	**38.5**	**12.5**	**16.7**	1.5	2.3	1.6	0.9	0.9	0.6	14	8	57.1
Jun '98	**25.7**	**25.0**	**24.3**	**21.9**	**19.7**	**21.4**	**10.6**	**7.7**	<.01	<.01	0.2	<.01	<.01	<.01	14	8	57.1
Jul '98	**18.4**	**23.8**	**22.7**	**17.7**	**14.8**	**22.7**	**7.0**	**5.7**	<.01	0.4	0.7	<.01	<.01	<.01	14	7	50.0
Aug '98	**24.2**	**29.0**	**16.8**	**27.3**	**10.6**	**13.7**	**11.3**	<.01	1.2	<.01	0.8	0.01	<.01	<.01	14	8	57.1
Sep '98	**28.4**	**36.9**	**22.8**	**30.6**	**12.1**	**35.9**	**9.8**	**7.8**	0.3	1.0	<.01	0.8	<.01	.01	14	8	57.1
Oct '98	**18.3**	**54.5**	**21.3**	**29.5**	**20.0**	**19.5**	1.0	**4.5**	**9.5**	**3.0**	0.7	**2.5**	**2.5**	0.7	14	11	78.6
Nov '98	**17.3**	**17.9**	**27.3**	**10.3**	**18.8**	**14.1**	**2.1**	**1.6**	1.2	0.6	0.9	0.6	0.2	<.01	14	8	57.1
Dec '98	**12.3**	**13.4**	**31.1**	**28.1**	**27.1**	**20.9**	**13.8**	**8.8**	<.01	0.9	0.3	0.9	0.01	0.6	14	8	57.1
Jan '99	**61.8**	**52.8**	**54.5**	**38.9**	**50.9**	**44.4**	**14.2**	**8.9**	0.4	0.3	0.4	0.3	<.01	<.01	14	8	57.1
Feb '99	**18.8**	**91.0**	**37.5**	**50.0**	**34.4**	**45.5**	**10.6**	**4.5**	**1.6**	**2.3**	**1.9**	**2.3**	0.6	0.5	14	12	85.7
Mar '99	**43.8**	**50.0**	**18.8**	**21.7**	**17.5**	**19.3**	**8.8**	**10.0**	0.9	1.0	0.6	1.0	0.3	0.3	14	8	57.1
Apr '99	**38.6**	**43.2**	**29.8**	**27.3**	**25.5**	**22.9**	**2.0**	**1.6**	0.9	**2.5**	0.7	**2.0**	0.5	**1.6**	14	11	78.6
May '99	**32.5**	-	**23.0**	-	**19.5**	-	**17.0**	-	**2.7**	-	**4.2**	-	0.6	-	7	6	85.7
Jun '99	**24.0**	**24.0**	**25.5**	**25.7**	**28.0**	**25.5**	0.4	0.4	**1.6**	0.8	1.3	0.8	0.7	0.2	14	7	50.0
Jul '99	-	**21.3**	-	**17.0**	-	**19.6**	-	1.3	-	1.5	-	1.3	-	0.4	7	3	42.8
Aug '99	**28.0**	**31.5**	**22.0**	**16.8**	**17.0**	**23.4**	**7.8**	**6.9**	0.8	**1.8**	0.4	0.9	<.01	0.8	14	9	64.3
Sep '99	-	**36.2**	-	**35.8**	-	**34.1**	-	**21.4**	-	**1.6**	-	1.3	-	2.8	7	5	71.4
Oct '99	**24.5**	**47.2**	**20.0**	**15.1**	**15.5**	**18.9**	**8.3**	**15.1**	<.01	0.4	<.01	0.4	<.01	<.01	14	8	57.1
Nov '99	**20.0**	**4.0**	**32.9**	**20.0**	**21.4**	**22.0**	**22.9**	**10.0**	0.5	0.2	0.5	0.2	0.1	0.1	14	8	57.1
Dec '99	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Highlighted Values → Values above Ghana EPA Maximum Permissible Limit (1.5 mg l^{-1})

Appendix 14 Ctd.

Summary of Key Environmental Issues (from Table A14.3):

(i) Over the two-year period, with the exception of three months (July 1998, June 1999 and July 1999), for each month, more than 50% of samples analysed had Arsenic concentrations above the EPAMPL, with concentrations as high as 60 times the EPAMPL measured in the Pompora Decant Water (*MS1) in February 1998

(ii) In the Kwabrafo River (**MS4), as much as 84% of water samples analysed over the two-year period had Arsenic concentrations exceeding the EPAMPL, with very high Arsenic concentrations in the dry months of each year (e.g. nearly 16 times the EPAMPL in November 1998)

Table A14.4: AGC (Obuasi) Water Quality Monitoring Results – Total Iron (mg l^{-1})

	*MS1		*MS2		*MS3		**MS4		*MS5		*MS6		**MS7		*TNS	TNS > *EPAMPL	% (TNS) > EPAMPL
Month / Year	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late			
Jan '98	0.3	0.05	0.19	0.10	0.25	<.01	0.19	<.01	0.13	0.13	0.4	0.3	0.19	0.25	14	Nil	Nil
Feb '98	1.4	**2.6**	0.8	0.2	0.6	0.2	0.03	0.02	<.01	0.01	0.21	0.24	0.02	0.01	14	1	7.1
Mar '98	0.09	0.08	0.08	0.03	0.01	0.02	0.02	0.03	0.06	0.12	0.09	0.07	0.24	0.09	14	Nil	Nil
Apr '98	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
May '98	0.06	0.07	0.06	0.01	<.01	0.01	0.02	0.02	0.01	<.01	0.04	0.02	0.06	0.08	14	Nil	Nil
Jun '98	1.1	0.1	0.02	0.2	0.02	0.9	<.01	0.2	0.2	0.1	0.2	0.3	0.1	0.1	14	Nil	Nil
Jul '98	**2.5**	1.48	0.04	0.27	0.23	0.02	0.08	<.01	0.5	2.0	0.08	0.7	0.03	0.04	14	1	7.1
Aug '98	0.09	0.3	0.3	0.1	0.1	0.2	0.01	0.1	0.1	0.1	<.01	0.1	<.01	0.02	14	Nil	Nil
Sep '98	**4.7**	1.2	**3.2**	0.04	0.1	0.5	0.1	0.1	0.2	0.1	0.1	0.04	<.01	0.02	14	2	14.3
Oct '98	**3.5**	1.7	0.2	0.4	0.3	0.3	0.04	0.1	**8.7**	0.8	0.13	0.1	0.7	0.03	14	2	14.3
Nov '98	1.1	0.9	0.07	0.1	0.09	0.1	0.04	0.1	0.07	0.1	0.07	0.04	0.03	0.01	14	Nil	Nil
Dec '98	0.4	0.03	0.03	<.01	0.04	<.01	0.04	0.1	0.03	0.03	0.03	0.03	0.01	0.1	14	Nil	Nil
Jan '99	1.1	0.9	0.5	0.4	0.4	0.4	0.1	0.04	<.01	<.01	<.01	<.01	0.01	<.01	14	Nil	Nil
Feb '99	0.8	**3.8**	0.4	0.1	0.4	0.1	0.04	0.02	<.01	<.01	<.01	<.01	0.01	<.01	14	1	7.1
Mar '99	0.05	0.07	0.01	0.01	0.01	0.01	0.01	0.03	0.05	0.03	0.06	0.03	0.3	0.06	14	Nil	Nil
Apr '99	0.1	0.07	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.04	0.02	0.07	0.2	0.2	14	Nil	Nil
May '99	0.02	-	<.01	-	<.01	-	<.01	-	<.01	-	<.01	-	0.08	-	7	Nil	Nil
Jun '99	<.01	0.02	<.01	<.01	<.01	0.02	<.01	<.01	<.01	<.01	<.01	<.01	0.03	0.02	14	Nil	Nil
Jul '99	-	<.01	-	<.01	-	<.01	-	<.01	-	<.01	-	<.01	-	<.01	7	Nil	Nil
Aug '99	0.02	0.01	0.02	0.03	0.01	0.02	0.01	0.01	**9.7**	**8.6**	**8.3**	0.8	0.03	0.04	14	3	21.4
Sep '99	-	0.04	-	0.04	-	0.07	-	0.28	-	<.01	-	<.01	-	0.03	7	Nil	Nil
Oct '99	1.1	4.3	0.5	0.2	0.5	0.5	0.5	0.5	0.07	0.08	0.07	0.05	0.07	0.2	14	Nil	Nil
Nov '99	0.07	0.07	0.04	0.07	0.06	0.02	0.16	<.01	0.03	<.01	<.01	<.01	<.01	<.01	14	Nil	Nil
Dec '99	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Highlighted Values → Values above Ghana EPA Maximum Permissible Limit (2 .0 mg l^{-1})

Appendix 14 Ctd.

Summary of Key Environmental Issues (from Table A14.4):

With the exception of 10 occasions (3.5% of cases) when the EPAMPL was exceeded, Iron concentrations were within the EPAMPL at all times over the two-year monitoring period. The 10 cases comprised 5 samples from the Pompora Decant (February, 1998, July 1998, September 1998, October 1998 and February 1999), 3 samples from the Sansu Tailings Dam (October, 1998, Early August 1999 and Late August 1999), a sample from the Coffer Dam upstream of the Kwabrafo River (September 1998) and a sample from the Sansu Holding Pond (August 1999)

Table A14.5: AGC (Obuasi) Water Quality Monitoring Results – Lead (mg l^{-1})

Month / Year	*MS1		*MS2		*MS3		**MS4		*MS5		*MS6		**MS7		*TNS	TNS > *EPAMPL	% TNS > EPAMPL
	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late			
Jan '98	**0.13**	<.01	<.01	<.01	**0.28**	<.01	<.01	<.01	<.01	**0.38**	**0.4**	**0.31**	<.01	**0.38**	14	6	42.8
Feb '98	<.01	<.01	<.01	0,01	0.02	0.01	0.01	0.08	0.01	<.01	0.03	0.02	0.01	**0.21**	14	1	7.1
Mar '98	0.04	<.01	<.01	0.01	0.03	0.01	0.01	<.01	**0.18**	**0.16**	**0.18**	**0.18**	0.08	0.07	14	4	28.6
Apr '98	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
May '98	0.02	0.01	<.01	0.01	<.01	0.01	0.01	<.01	<.01	0.01	0.02	0.01	<.01	<.01	14	Nil	Nil
Jun '98	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	14	Nil	Nil
Jul '98	0.03	<.01	0.03	<.01	0.03	<.01	0.05	<.01	0.05	0.1	**0.2**	0.1	**0.2**	0.05	14	2	14.3
Aug '98	<.01	0.05	0.1	0.05	0.06	0.05	0.1	0.05	0.01	0.1	0.02	0.1	0.01	0.1	14	Nil	Nil
Sep '98	0.1	0.03	0.1	<.01	<.01	0.03	0.01	0.03	0.1	0.2	0.1	0.1	<.01	0.1	14	Nil	Nil
Oct '98	0.09	<.01	0.09	<.01	0.07	<.01	0.07	<.01	**0.2**	**0.2**	**0.16**	**0.2**	0.09	0.03	14	4	28.6
Nov '98	0.1	**0.3**	0.1	**0.2**	0.08	**0.3**	0.1	**0.2**	**0.3**	**0.3**	**0.2**	**0.4**	**0.2**	**0.2**	14	10	71.4
Dec '98	**0.3**	<.01	**0.2**	<.01	**0.2**	<.01	0.1	<.01	**0.3**	0.1	**0.2**	<.01	**0.2**	**0.2**	14	7	50.0
Jan '99	<.01	0.1	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	14	Nil	Nil
Feb '99	<.01	0.1	<.01	<.01	<.01	<.01	<.01	0.13	<.01	<.01	0.02	<.01	<.01	<.01	14	Nil	Nil
Mar '99	<.01	<.01	<.01	<.01	0.06	<.01	<.01	<.01	**0.16**	**0.2**	**0.16**	**0.19**	0.09	0.03	14	4	28.6
Apr '99	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	14	Nil	Nil
May '99	<.01	-	<.01	-	<.01	-	<.01	-	<.01	-	<.01	-	<.01	-	7	Nil	Nil
Jun '99	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	14	Nil	Nil
Jul '99	-	<.01	-	<.01	-	<.01	-	<.01	-	<.01	-	<.01	-	<.01	7	Nil	Nil
Aug '99	0.03	0.01	0.02	0.06	0.04	0.06	<.01	0.01	0.20	0.04	**0.18**	**0.2**	0.03	<.01	14	2	14.3
Sep '99	-	<.01	-	<.01	-	<.01	-	<.01	-	<.01	-	<.01	-	<.01	7	Nil	Nil
Oct '99	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	14	Nil	Nil
Nov '99	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.1	<.01	**0.14**	<.01	<.01	<.01	<.01	14	1	7.1
Dec '99	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Highlighted Values → Values above Ghana EPA MPL (0.1 mg l^{-1})

Appendix 14 Ctd.

Summary of Key Environmental Issues (from Table A14.5):

(i) Relatively few (38 out of the 287 [13.2%] samples analysed over the two-year period had lead concentrations exceeding the EPAMPL, with all but two of the 38 'above-EPAMPL' samples measured during the dry months of the year

(ii) On one occasion (November 1998), the concentration of Lead in the Kwabrafo River exceeded the EPAMPL, while on 6 occasions (January 1998, February 1998, July 1998, Early November 1998, Late November 1998, Early December 1999 and Late December 1999), water samples from River Nyam had Lead concentrations two to three times above the EPAMPL

Table A14.6: AGC (Obuasi) Water Quality Monitoring Results – Conductivity (µS/cm)

Month / Year	*MS1		*MS2		*MS3		**MS4		*MS5		*MS6		**MS7		*TNS	TNS > *EPAMPL	% (TNS) > EPAMPL
	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late			
Jan '98	1510	2346	1887	1586	1544	1454	1745	1233	2400	4500	4000	4400	1586	2500	14	14	100
Feb '98	1594	2210	2130	1958	2214	1536	1621	1583	2536	2374	3267	2859	1486	1325	14	14	100
Mar '98	1896	2113	2138	1843	2097	1941	1827	1720	2087	3421	3213	2118	1978	1113	14	14	100
Apr '98	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
May '98	2063	2130	1897	1902	2058	2017	1803	1837	2785	2981	2996	2857	2106	2210	14	14	100
Jun '98	1843	2290	1725	1904	1583	1880	1754	1761	5350	4780	5150	4920	2150	2460	14	14	100
Jul '98	1815	2090	1887	1687	1775	1870	1754	1761	5350	4790	5150	4920	2150	2460	14	14	100
Aug '98	1320	2300	1430	2310	1800	2150	890	950	2780	2950	2780	2850	1220	1085	14	14	100
Sep '98	2700	2170	2411	2150	2220	2340	1440	1530	6750	6670	6550	6668	1318	2380	14	14	100
Oct '98	2480	2080	2270	2050	1990	1980	1507	1404	5080	4410	5720	5710	2820	1113	14	14	100
Nov '98	2150	2520	2260	2320	1940	2170	1708	1420	5980	3958	4750	3942	2150	855	14	14	100
Dec '98	1777	1380	1707	1160	1565	1110	930	680	3900	3290	2500	3410	900	1120	14	14	100
Jan '99	2114	2214	2100	2040	2090	2146	1975	1897	2837	2637	2840	2634	1607	1574	14	14	100
Feb '99	2010	2061	1967	2050	2001	2056	1624	1660	2437	1971	2456	1975	1459	1035	14	14	100
Mar '99	2167	1949	2084	1874	2124	1912	1848	1667	3944	1972	3897	1949	2014	1007	14	14	100
Apr '99	2124	2325	2076	2189	2092	2124	1894	1914	2986	3012	2947	3024	1200	3143	14	14	100
May '99	2045	-	1946	-	2007	-	1828	-	2889	-	2787	-	2908	-	7	7	100
Jun '99	2415	2410	2168	2097	2344	2387	2000	1943	3014	3106	3008	3120	2914	3100	14	14	100
Jul '99	-	2004	-	1878	-	1914	-	1724	-	3010	-	3004	-	3015	7	7	100
Aug '99	2110	2213	1912	1942	2006	2135	1647	1851	2984	3001	2786	3115	3004	3017	14	14	100
Sep '99	-	1884	-	1821	-	1876	-	1742	-	1507	-	1504	-	1000	7	7	100
Oct '99	2010	1842	1874	1699	1879	1606	960	890	3914	3996	3878	3849	990	1425	14	14	100
Nov '99	1425	1096	1545	2068	1557	2093	1000	1240	4870	4847	5010	4990	1588	1567	14	14	100
Dec '99	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Highlighted Values → Values above Ghana EPA Maximum Permissible Limit (750 µS/cm)

Appendix 14 Ctd.

Summary of Key Environmental Issues (from Table A14.6):

All samples anaysed over the 24-month period had conductivity rates exceeding the EPAMPL, with as much as 92% of the samples (265 out of the total of 287 samples analysed) having conductivities more than twice the EPAMPL

Table A14.7: AGC (Obuasi) Water Quality Monitoring Results –Total Suspended Solids (mg l^{-1})

	*MS1		*MS2		*MS3		**MS4		*MS5		*MS6		**MS7		*TNS	TNS > *EPAMPL	% TNS > EPAMPL
Month / Year	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late			
Jan '98	**67**	23	42	19	33	18	**163**	**260**	50	15	34	13	24	21	14	3	21.4
Feb '98	13	18	21	18	17	11	43	**67**	36	28	15	8	22	16	14	1	7.1
Mar '98	32	48	12	8	11	9	42	**58**	**53**	18	19	12	33	19	14	2	14.3
Apr '98	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
May '98	18	26	10	7	25	17	33	42	15	13	18	22	21	20	14	Nil	Nil
Jun '98	38	36	18	6	42	12	10	**168**	**70**	14	12	12	14	6	14	2	14.3
Jul '98	**80**	31	26	12	28	25	34	**69**	**56**	28	**402**	13	10	5	14	4	28.6
Aug '98	**68**	36	27	30	4	14	**86**	**446**	26	16	30	20	26	22	14	3	21.4
Sep '98	**78**	18	**52**	21	36	14	**450**	20	**76**	15	**58**	15	**56**	19	14	6	42.8
Oct '98	**176**	35	20	2	10	23	10	23	**114**	31	34	31	22	22	14	2	14.3
Nov '98	**96**	**248**	14	44	26	2	42	40	50	24	**66**	20	28	30	14	3	21.4
Dec '98	40	38	24	16	20	12	14	**184**	40	10	48	22	6	18	14	1	7.1
Jan '99	22	10	16	18	16	12	38	32	8	22	6	16	10	24	14	Nil	Nil
Feb '99	6	9	6	6	5	8	30	41	9	8	6	16	10	24	14	Nil	Nil
Mar '99	24	**62**	8	4	6	4	24	34	50	12	22	10	30	16	14	1	7.1
Apr '99	16	8	10	16	12	8	**140**	92	14	10	12	12	24	28	14	1	7.1
May '99	10	-	6	-	8	-	30	-	10	-	10	-	35	-	7	Nil	Nil
Jun '99	**62**	14	**82**	14	**90**	20	26	24	10	10	30	24	4	8	14	3	21.4
Jul '99	-	20	-	10	-	14	-	34	-	14	-	24	-	28	7	Nil	Nil
Aug '99	4	16	2	8	10	21	20	33	44	18	38	29	12	17	14	Nil	Nil
Sep '99	-	24	-	8	-	16	-	40	-	10	-	30	-	4	7	Nil	Nil
Oct '99	**106**	20	5	3	11	8	**137**	42	9	**64**	14	12	14	14	14	3	21.4
Nov '99	18	13	5	8	15	17	45	36	**125**	18	**123**	6	**72**	16	14	3	21.4
Dec '99	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Highlighted Values → Values above Ghana EPA Maximum Permissible Limit (50 mg l^{-1})

Appendix 14 Ctd.

Summary of Key Environmental Issues (from Table A14.7):

Concentrations of suspended solids were generally low month after month throughout the two-year monitoring period, with only 38 of the 287 samples analysed (13% of samples) having suspended sold concentrations above the EPAMPL. It is however worrying that a third of the samples above the EPAMPL were from the Kwabrafo River (**MS4), with suspended solid concentrations as high as 9 times the EPAMPL measured in August and September 1998

APPENDIX 15

Summary: RAL Water Quality Monitoring Data: 1998 – 1999

Table A15.1: Water Quality Monitoring Results for Monthly samples taken at RAL's Water Effluent Discharge Point (where water from the wetland filter enters the Ayensu Creek)

Mth / Yr	pH (pH Units) *EPAMPL: 6 - 9*	Free Cyanide (mg / l) *EPAMPL: 0.1 mg / l*	Total Cyanide (mg / l) *EPAMPL: 1.0 mg / l*	Total Arsenic (mg / l) *EPAMPL: 1.5 mg / l*	Total Susp. Solids (mg / l) *EPAMPL: 50 mg / l*	Conductivity (μS / cm) *EPAMPL: 750 μS / cm*
Jan'98	6.6	< 0.01	0.01	0.11	36.4	33.3
Feb'98	8.7	< 0.01	0.01	0.06	42.8	38.6
Mar'98	7.8	< 0.01	0.01	0.07	37.2	45.4
Apr'98	7.2	< 0.01	0.02	0.09	39.4	82.2
May'98	6.8	0.01	0.02	0.07	**56.8**	52.6
Jun'98	6.8	0.01	0.06	0.13	41.6	30.8
Jul'98	6.6	0.01	**1.58**	0.01	44.2	32.3
Aug'98	6.4	0.01	0.01	0.09	42.3	58.9
Sep'98	7.3	0.01	0.01	0.10	33.4	72.5
Oct'98	6.6	0.01	0.01	0.02	39.4	68.2
Nov'98	6.8	<0.01	0.01	0.12	42.7	54.6
Dec'98	6.7	0.01	0.01	0.16	36.5	34.7
Jan'99	6.9	0.01	0.01	0.10	38.3	48.6
Feb'99	7.5	0.01	0.01	0.02	38.8	41.7
Mar'99	8.6	< 0.01	0.01	0.06	69.1	43.5
Apr'99	7.4	< 0.01	0.01	0.14	32.6	35.2
May'99	6.8	0.01	0.01	0.50	48.1	38.5
Jun'99	7.4	0.01	0.01	0.05	46.8	34.3
Jul'99	7.1	0.01	0.01	0.10	**63.7**	48.1
Aug'99	7.1	0.01	0.01	0.15	42.6	60.5
Sep'99	6.9	0.01	0.01	0.01	38.4	40.2
Oct'99	7.0	0.01	0.01	0.12	41.1	47.4
Nov'99	7.6	0.01	0.03	0.06	**164.2**	35.0
Dec'99	8.0	0.01	0.01	0.01	37.8	49.2

Highlighted Values → Values above Ghana EPA Maximum Permissible Limit

Summary of Key Environmental Issues (from Table A15.1):

*The Ghana EPA Maximum Permissible Limit (EPAMPL) was exceeded only on the following four occasions throughout the two-year monitoring period:

- July 1998 : Total Cyanide (mg / l)
- May 1998 : Total Suspended Solids (mg / l)

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- July 1999 : Total Suspended Solids (mg / l)
- November 1999: Total Suspended Solids (mg / l)

* On no occasion did pH, Free Cyanide and Total Arsenic levels, and, Conductivity rates exceed the Ghana EPA Maximum Permissible Limit throughout the two-year monitoring period

APPENDIX 16

Summary: BGM Water Quality Monitoring Data: 1998 – 1999

Table A16.1: BGM's Water Quality Monitoring Results: January 1998 – December1999

	PH (pH Units) * EPAMPL: 6 - 9					Turbidity (N.T.U.) * EPAMPL: 75 N.T.U.					Total Dissolved Solids (mg / l) EPAMPL: 50 mg / l					Conductivity (µS / cm) EPAMPL: 750 µS / cm				
Mth / Yr	MP1	MP2	MP3	MP4	MP5	MP1	MP2	MP3	MP4	MP5	MP1	MP2	MP3	MP4	MP5	MP1	MP2	MP3	MP4	MP5
Jan'98	6.9	6.1	6.4	6.3	6.9	15.8	8.2	04	0.4	11.2	**171**	**169**	**169**	**213**	**115**	379	325	366	346	184
Feb'98	7.0	6.4	5.9	6.9	7.4	11.3	5.3	0.5	0.4	36.4	**311**	**171**	**173**	**214**	**113**	444	358	364	348	237
Mar'98	6.9	6.5	6.0	6.7	7.5	4.4	20.4	1.1	4.9	15.9	**198**	**152**	**138**	**108**	**108**	483	384	329	269	269
Apr'98	7.1	6.6	6.0	6.7	7.0	3.6	3.8	0.7	2.4	29.4	**130**	**164**	**167**	**199**	**80**	311	392	401	470	150
May'98	6.9	6.2	6.1	6.8	6.9	3.6	7.2	0.8	5.9	48.2	**140**	**153**	**162**	**181**	**96**	386	390	386	400	191
Jun'98	6.7	6.5	6.1	6.5	7.1	1.7	4.8	6.7	39.9	36.1	**204**	**160**	**161**	**154**	**89**	428	338	340	325	189
Jul'98	7.1	6.5	6.1	6.6	7.1	13.3	20.0	1.2	24.1	23.9	**216**	**163**	**169**	**167**	**76**	455	342	356	350	160
Aug'98	7.0	6.8	6.0	6.6	7.4	5.0	17.1	0.6	24.4	17.2	**205**	**164**	**168**	**166**	**82**	423	344	353	351	173
Sep'98	6.7	6.3	**5.8**	6.2	7.4	18.3	17.8	1.1	35.7	28.9	**195**	**161**	**166**	**162**	**75**	408	340	349	342	158
Oct'98	6.9	6.2	**5.7**	6.6	6.1	8.8	19.3	0.4	17.6	13.4	**213**	**149**	**156**	**163**	**149**	448	313	350	133	315
Nov'98	6.9	6.4	**5.8**	6.2	7.6	13.7	1.6	0.6	20.5	18.7	**205**	**163**	**164**	**160**	**81**	431	345	347	331	171
Dec'98	7.1	6.4	**5.8**	6.4	7.3	13.5	3.1	0.4	17.4	14.5	**212**	**161**	**166**	**165**	**101**	445	341	350	347	212
Jan'99	6.8	6.3	**5.8**	6.4	7.3	14.9	6.6	0.5	0.6	9.8	**219**	**158**	**171**	**192**	**97**	426	347	318	337	105
Feb'99	6.8	6.6	6.1	6.5	6.9	18.8	8.9	0.9	0.7	8.7	**185**	**163**	**178**	**188**	**119**	396	362	321	356	179
Mar'99	7.0	6.3	6.2	6.6	7.3	11.3	8.3	0.8	21.3	12.8	**207**	**148**	**157**	**224**	**128**	393	391	286	291	251
Apr'99	7.0	6.7	**5.8**	6.8	6.9	5.8	9.6	1.2	15.1	21.5	**145**	**161**	**148**	**206**	**101**	306	347	358	386	203
May'99	6.9	6.5	6.2	6.5	7.0	12.8	12.1	0.6	4.2	13.7	**163**	**152**	**157**	**221**	**89**	403	396	364	335	186
Jun'99	6.8	6.4	6.1	6.7	6.9	8.7	5.2	1.4	12.6	29.3	**187**	**176**	**172**	**194**	**123**	421	351	348	421	178
Jul'99	6.9	6.6	6.1	6.7	6.8	9.8	14.1	0.6	17.2	29.6	**196**	**185**	**146**	**178**	**94**	426	382	388	286	227
Aug'99	6.8	6.7	**5.9**	7.2	7.2	11.6	8.8	1.1	22.4	16.4	**189**	**152**	**174**	**198**	**122**	398	315	338	404	162
Sep'99	7.0	6.8	6.2	7.2	7.1	13.7	16.3	1.6	29.6	25.5	**192**	**165**	**178**	**206**	**136**	425	326	336	398	175
Oct'99	7.1	6.4	6.1	6.6	7.2	12.8	14.5	0.8	9.4	22.7	**222**	**162**	**173**	**176**	**138**	431	362	368	286	186
Nov'99	7.1	6.7	**5.9**	6.5	7.4	14.6	10.4	1.6	27.2	17.4	**197**	**173**	**158**	**180**	**105**	391	355	355	396	219
Dec'99	7.0	6.3	6.0	6.8	7.3	9.7	8.4	0.9	18.6	13.8	**216**	**161**	**168**	**174**	**92**	422	348	354	415	107

Highlighted Values → Values above EPAMPL

MP1 = Borehole at BGM Minesite; **MP2** = Borehole at BGM Campsite; **MP3** = Borehole at Tetrem;

MP4 = Hand-dug well at Manhyia; **MP5** = River Ofin at 'Pump Station'

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Summary of Key Environmental Issues (from Table A16.1):

pH: EPAMPL was exceeded on only 8 occasions (13.3% of samples) throughot the two-year monitoring period, with all the samples exceeding the EPAMPL being from a borehole at the BGM Campsite

***Turbidity**:* Surprisingly, on no occasion was the EPAMPL exceeded throughout the two-year monitoring period

***Total Dissolved Solids**:* The EPAMPL was exceeded at all the monitoring sites for the entire two-year monitoring period, with the EPAMPL exceeded three times in 72% of the samples analysed

***Conductivity**:* On no occasion did conductivity rates exceed the EPAMPL throughout the two-year monitoring period at all the sampling sites

APPENDIX 17

Questionnaire for Data Collection from Mining Companies

This questionnaire is designed to help obtain information that will be used in assessing the environmental and social impacts of surface gold mining in southern Ghana and ways of mitigating these impacts. This is a Postgraduate (PhD) research project supported by the Department Of Environmental Science, University Of Stirling (Scotland). Kindly supply the required information in the spaces provided below. You are assured that information you provide will be treated with strictest confidentiality.

MANAGEMENT / ENVIRONMENTAL MANAGERS

1. a) **Name of Company** ....
   b) **District**..
   c) **Region**...
   d) **Geographical Location of Mine**...
   ....
   ....

2. **How long have you been operating this mine?**
   ☐ Less than 1 year
   ☐1-5 years
   ☐ 5-10 years
   ☐10-20 years
   ☐More than 20 years

   *Year of Commencement of mining Operations...................

3. **State the area of the mining concession** ....ha

4. **State the area of the concession occupied by current mining operations...........ha**

5. **Outline any statutory requirements that had to be fulfilled (including permits, Licences, etc., obtained) prior to commencement of mining operations and the responsible institutions, in the table below:**

↓

↓

STATUTORY REQUIREMENT	INSTITUTION INVOLVED
i.	
ii.	
iii.	
iv.	
v.	
vi	
vii.	
viii.	
ix.	
x.	

6. **Were baseline studies conducted on the concession and its environs prior to commencement of mining operations?**

☐ Yes　　　　　No ☐

↓ (*Go to Q7*)

7. **Did you employ any standard methodologies or techniques in your baseline studies (ecological surveys, background levels of 'important' gases, metals, etc.)?**

☐ Yes　　　　　No ☐

↓ (*Go to Q8*)

8. **Briefly outline the methodology / techniques employed in the acquisition of your baseline data in the table below :**

↓

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↓

BASELINE DATA ACQUIRED	METHODOLOGY / TECHNIQUE USED
i.	
ii.	
iii.	
iv.	
v.	
vi	
vii.	
viii.	
ix.	
x.	
xi.	
xii.	
xiii.	
xiv	

9. Is there a report (eg. Environmental Impact Statement) in which findings of the baseline studies were documented?

☐ Yes No ☐

↓

(Could you please provide relevant pages of the report)

PLANNING AND DESIGN

10. In what ways did the results of the baseline studies (information on location of rivers, streams, water catchment characteristics, presence of natural buffer zones, corridors, conservation areas and habitations of rural communities, terrain features, wind direction, vegetal cover, hydrogeology, soil types, faunal habitats, sites of special significance / value, etc.,) affect 'Planning and Design' of the following features, for environmentally friendly and socially responsive mining operations?

a. *Exploration / prospecting (techniques)*--

b. *Bulk sampling*--

c. *Site preparation*--

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d. *Mine layout (location of)*:

i. mine site buildings

ii. settlement areas

iii. crushing and milling operations

iv. leaching operations

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v. tailings dams

vi. settling ponds

vii. smelting / refinery facilities

viii. fuel dumps

ix. haulage / access roads--

x. drainage systems--

11. State the main beneficial impacts of your mining operations:

12. State the main adverse impacts of your mining operations:

----

13. Were environmental considerations taken into account in the choice of mining equipment and types of mining techniques applied?

↓

☐ Yes No ☐

↓

State the measures (including technique / technology) employed to minimise environmental and social impacts of mining operations by completing the table below:

↓

ACTIVITY	TECHNIQUE / TECHNOLOGY APPLIED	EFFECT
i. Exploration		
ii. Bulk sampling		
iii. Site preparation		
iv. Drilling works		
v. Blasting		
vi. Excavation works		
vii. Loading / Haulage		
viii. Crushing / Milling		
ix. Leaching / Concentration		
x. Smelting / Refinery		

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OREBODY CHARATERISTICS, CHEMICALS USED, ETC., AND THEIR IMPLICATIONS FOR ENVIRONMENTAL MANAGEMENT

14. What chemically active materials accompany gold mineralization in your concession area? Pyrites☐ Arsenopyrites☐ Diorites☐ Granodiorites☐ Prophyry☐

Others--- (Please, Specify)

15. State the nature of the ore deposits:
Clayey☐ Sandy☐ Silty☐ Gravelly☐ Other..............(Please, Specify)

16. Provide information on the types of chemicals and reagents used at various stages of the mining process and outline measures taken to minimise environmental impacts associated with their use in the table below :

OPERATION / PROCESS	CHEMICALS/ REAGENTS USED	MITIGATION MEASURES
i. Drilling		
ii. Blasting		
iii. Beneficiation		
iv. Leaching / Concentration		
v. Recovery		
vi. Refinery		
OTHERS		

17. Are specific programmes in place to check environmental degradation and pollution?

☐ Yes No ☐

↓

a. Explain how environmental problems created by mining activities are being tackled by completing the table below:

PROBLEM	MITIGATION MEASURES
Air Pollution ⇒ • Dust • Noise • Gaseous Pollutants associated with ore body and processing chemicals: - i.................. ii.................. iii.................. iv.................. v .... vi.................. vii..................	
Soil Pollution...from: • Acid drainage • Oil residue • Heavy metals: i.............. ii.............. iii.............. iv.............. v.............. vi.............. • Process chemicals i.............. ii.............. iii.............. iv.............. v.............. vi..............	

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↓

PROBLEM	MITIGATION MEASURES
Surface Water Pollution…from: • Sedimentation • Acid drainage • Oil residue • Heavy metals: i…………… ii…………… iii…………… iv…………… v…………… vi…………… • Process chemicals i…………… ii…………… iii…………… iv…………… v…………… vi……………	
Ground Water Pollution…from: • Acid drainage • Oil residue • Heavy metals i…………… ii…………… iii…………… iv…………… v…………… vi…………… • Process chemicals i…………… ii…………… iii…………… iv…………… v……………	
Destruction of vegetal cover	

↓

PROBLEM	MITIGATION MEASURES
Elimination / Destruction of terrestrial & aquatic organisms	
Others: • • • • • • •	

b. With regard to air, soil and water pollution as outlined in the table above, could you please indicate the average concentrations of the pollutants in samples that are discharged into the environment in the table below:

POLLUTANT	CONCENTRATION (mg/l)	RECEIVING MEDIUM
i.		
ii.		
iii.		
iv.		
v.		
vi.		
vii.		
viii.		
ix.		
x.		
xi.		
xii.		
xiii.		
xiv		

c. Are there specific guidelines and standards (environmental guidelines, regulations, policies, etc.) from government and industry that guide the disposal of wastes from your operations into the environment?

☐ Yes No ☐

↓

State them (or provide copies if possible)

↓

↓

↓

d. Are tailings from your operations channelled into dams?

☐ Yes No ☐→ *☐ Discharged directly into a river / stream after treatment
↓ ☐ Discharged directly into a river / stream without treatment
*☐ Discharged directly onto adjoining land after treatment
☐ Discharged directly onto adjoining land without treatment
☐ Other--(Please, specify)

* Briefly explain how the tailings are treated before disposal
----

↓

e. What features characterise the area in which your
↓ concession is located?

☐ Heavy rains accompanied by flooding
☐ Highly porous soils
☐ Highly leached soils
☐ Hilly terrain
☐ Other ---

---(Please specify)

↓

f. What materials were used for the construction of:

i. The walls of the tailings dam? --

ii. The basement of the dam? --

g. What method was used in the construction of the dam?

☐ Upstream method ☐ Downstream method ☐ Central Line method

☐ Other---(Please specify)

h. What techniques are employed to reduce pollution of ground water through:

i. **Seepage of leachates from the tailings dam?** ---

ii. **Seepage of leachates from (waste) settling ponds?**---

iii. **Seepage of leachates from waste dumps?**

i. What techniques are employed to minimise surface water pollution from:

i. **Spillovers from the tailings dam?**

ii. **Spillovers from (waste) settlement ponds?**

iii. **Runoff from waste dump sites?**

iv. **Runoff from the general mining area?**

18. Does the company have an environmental policy with clearly defined environmental management objectives?

☐ Yes   No ☐

↓

(Please, state them or provide a copy of the policy)--

----

19. Does the company have an Environmental Management Department?

☐Yes   No☐→**Who implements your environmental protection policy/objectives?**

↓

☐ Environmental Consultants
☐ Selected government agencies
☐ Selected private bodies
☐ Other------------------------------------(Please, specify)

CURRENT MONITORING

↓

20. Have environmental and other monitoring programmes been put in place at the mine?

☐ Yes   No ☐

↓

State the monitoring procedure and comment on the effectiveness of the monitoring programme in the table below:

↓

PARAMETER MONITORED	MONITORING PROCEDURE	COMMENTS
Surface Water Quality		
Ground Water Quality		
Air Quality		
Soil Quality		
Land Use (adjoining sites)		
Stream / River Water Use		
Fishery and Aquatic Resources		
Wildlife		

REHABILITATION / RECLAMATION / RESTORATION, ETC.

21. Will the site be rehabilitated / restored / reclaimed after cessation of mining operations

☐ Yes No ☐

↓

↓

a. Explain how this will be done and describe the perceived state of the various components of the site by completing the table below:

↓

AREA	REMEDIATION MEASURES	PERCEIVED STATE
i. Mine pits		
ii. Tailings dams		
iii. Settling ponds		
iv. Leaching operations site		
v. Spoils dump / Dump sites		
vi. Buildings / plants sites		
vii. Milling operations sites		
viii. Mineral recovery / refinery site		
OTHERS		

↓

b. What is the anticipated future land use of the site?

Agriculture☐ Forestry☐ Recreation☐ Residential☐ Other............. (Please, specify)

c. Were specific factors taken into account in the pre- determination of the ultimate land (end) use of the site?

☐ Yes No ☐

↓

State the factors that were considered:

☐ Restoration to original status
☐ Mimicking adjoining sites
☐ Site Characteristics (morphology, soil dynamics, etc.)
☐ Meeting demand of local community
☐ Others……………………………………………………………
……………………………………………………………
…………………………………………………………… (Please, specify)

FUTURE MONOTORING

22. Will environmental and other monitoring programmes be put in place at the above site after cessation of mining operations?

☐ Yes No ☐

↓

State the monitoring procedure and comment on the monitoring programme in the table below:

PARAMETER TO BE MONITORED	MONITORING PROCEDURE	COMMENTS
Surface Water Quality		
Ground Water Quality		
Soil Quality		
Land Use		
Stream / River Water Use		
Fishery and Aquatic Resources		
Wildlife		
Success of rehabilitation / reclamation / restoration programmes		

APPENDIX 18

Questionnaire for Data Collection from the General Community

This questionnaire is designed to help obtain information that will be used in assessing the environmental and social impacts of surface gold mining in southern Ghana and ways of mitigating these impacts. This is a Postgraduate (PhD) research project supported by the Department of Environmental Science, University of Stirling (Scotland). Kindly supply the required information in the spaces provided below. You are assured that information you provide will be treated with strictest confidentiality.

1. What is your occupation?

☐ Farmer
☐ Fisherman
☐ Hunter
☐ Housewife
☐ Mine worker
☐ Trader
☐ Public / Civil servant
☐ Other---------------------------- (please, specify)

2. How old are you?

☐ 20-30 years old
☐ 30-40 years old
☐ 40-50 years old
☐ 50-60 years old
☐ > 60 years old

3. Sex

Male ☐ Female ☐

4. Are you originally from this area?

☐ Yes No ☐

5. How long have you lived in this town / village / community?

☐ < 1 Year
☐ 1-10 Years
☐ 10-20 years
☐ 20-30 years
☐ > 30 years

6. What do you consider to be the 5 most remarkable positive impacts of mining operations in this area? (Briefly explain the nature of each impact)

Impact 1---

Impact 2---

Impact 3---

Impact 4---

Impact 5---

(Impacts may include: Creation of employment for local people; Provision of potable water; Establishment of schools; Provision of social amenities; Enhancement of trade; Promotion / enhancement of small scale industries; Improvement in road / road network)

7. What do you consider to be the 5 most serious negative impacts of mining operations in this area?

Problem 1--

Problem 2--

Problem 3--

Problem 4--

Problem 5--

(Impacts may include: Destruction of farms / farmlands; Air / Water / soil pollution; Difficulty in having access to game animals; Destruction of medicinal plants; Reduction in fish stocks; Problem of acquisition of fuelwood; High Cost of living)

8. Briefly explain the nature of the problems listed above:

Problem 1--

Problem 2--

Problem 3--

Problem 4--

Problem 5--

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9. Have steps (solution measures) been taken by the mining company operating in this region to solve the problems above?

☐ Yes   No ☐

↓

Please, state the solution measures below:

....
....
....
....
....
....
....
....
....
....

10. Please, list five impact mitigation measures that you think will be of great benefit to your community, which you would like the mining company operating in this area to embark upon (Please, give reasons if possible)

(Solution measures may include: Provision of adequate potable water; Rehabilitation / Restoration / Revegetation: Air / Water / Soil Pollution Reduction; Conservation of natural resources; Improvement in road conditions)

APPENDIX 19

Questionnaire for Data Collection from Farmers

This questionnaire is designed to help obtain information that will be used in assessing the environmental and social impacts of surface gold mining in southern Ghana and ways of mitigating these impacts. This is a Postgraduate (PhD) research project supported by the Department of Environmental Science, University of Stirling (Scotland). Kindly supply the required information in the spaces provided below. You are assured that information you provide will be treated with strictest confidentiality.

1. How long have you been residing in this area?

☐ < 1 year
☐ 1-10 years
☐ 10-20 years
☐ 20-30 years
☐ > 30 years

2. How long have you been involved in farming activities in this area?

☐ < 1 year
☐ 1-10 years
☐ 10-20 years
☐ 20-30 years
☐ > 30 years

3. What do you usually cultivate?

☐ Yam
☐ Cocoyam
☐ Plantain
☐ Cassava
☐ Maize
☐ Vegetables
☐ Other(s) --(Please, specify)

4. Have mining activities adversely affected your crop production levels over the years?

☐Yes No ☐
↓
How do you estimate the level of the impact?

☐ Negligible – Very Low (*0 – 25% fall in Annual Crop Production Level*)
☐ Low – Fairly High (*25 – 50% fall in Annual Crop Production Level*)
☐ High (*50 – 75% fall in Annual Crop Production Level*)
☐ Very High (*75 – 100% fall in Annual Crop Production Level*)

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5. **To the best of your knowledge, explain the nature of the above impact in the spaces below:**

APPENDIX 20

Questionnaire for Data Collection from Fishermen

This questionnaire is designed to help obtain information that will be used in assessing the environmental and social impacts of surface gold mining in southern Ghana and ways of mitigating these impacts. This is a Postgraduate (PhD) research project supported by the Department of Environmental Science, University of Stirling (Scotland). Kindly supply the required information in the spaces provided below. You are assured that information you provide will be treated with strictest confidentiality.

1. How long have you been residing in this area?

☐ < 1 year
☐ 1-10 years
☐ 10-20 years
☐ 20-30 years
☐ > 30 years

2. How long have you been involved in fishing activities in this area?

☐ < 1 year
☐ 1-10 years
☐ 10-20 years
☐ 20-30 years
☐ > 30 years

3. Are you currently engaged in fishing activities?

Yes ☐ No ☐

4. **How would you describe fish populations (in water bodies) in this area over the years?**

Stable ☐
Increasing ☐
Decreasing ☐

5. What, in your opinion, are the three most likely factors responsible for the trend in fish populations described above? (Please, state the nature of the impact caused by each of the listed factors)

Factor 1---
Factor 2---
Factor 3---

APPENDIX 21

Questionnaire for Data Collection from Hunters

This questionnaire is designed to help obtain information that will be used in assessing the environmental and social impacts of surface gold mining in southern Ghana and ways of mitigating these impacts. This is a Postgraduate (PhD) research project supported by the Department of Environmental Science, University of Stirling (Scotland). Kindly supply the required information in the spaces provided below. You are assured that information you provide will be treated with strictest confidentiality.

1. How long have you been residing in this area?

☐ < 1 year
☐ 1-10 years
☐ 10-20 years
☐ 20-30 years
☐ > 30 years

2. How long have you been involved in hunting activities in this area?

☐ < 1 year
☐ 1-10 years
☐ 10-20 years
☐ 20-30 years
☐ > 30 years

3. Are you currently engaged in hunting activities?

Yes ☐ No ☐

4. **How would you describe game animal populations in in this area over the years?**

Stable ☐
Increasing ☐
Decreasing ☐

5. What, in your opinion, are the three most likely factors responsible for the trend in game animal populations described above? (Please, state the nature of the impact caused by each of the listed factors)

Factor 1--
Factor 2--
Factor 3--

APPENDIX 22

Questionnaire for Data Collection from Housewives

This questionnaire is designed to help obtain information that will be used in assessing the environmental and social impacts of surface gold mining in southern Ghana and ways of mitigating these impacts. This is a Postgraduate (PhD) research project supported by the Department of Environmental Science, University of Stirling (Scotland). Kindly supply the required information in the spaces provided below. You are assured that information you provide will be treated with strictest confidentiality.

1. How long have you been residing in this area?

☐ < 1 year
☐ 1-10 years
☐ 10-20 years
☐ 20-30 years
☐ > 30 years

2. How long have you lived in this area as a housewife?

☐ < 1 year
☐ 1-10 years
☐ 10-20 years
☐ 20-30 years
☐ > 30 years

3. What fuel(s) do you use for domestic cooking? (tick as appropriate….[1] = the most frequently used fuel and [4] = the least frequently used fuel)

☐ Firewood	1☐	2☐	3☐	4☐
☐ Electricity	1☐	2☐	3☐	4☐
☐ Kerosine	1☐	2☐	3☐	4☐
☐ Gas	1☐	2☐	3☐	4☐
☐ Biogas	1☐	2☐	3☐	4☐
☐ Other	1☐	2☐	3☐	4☐

(Please, specify)------------------

4. If firewood is the most frequently used fuel, how do you obtain it?

☐ Fetch from the bush   Buy it ☐
↓

Appendix 22 Ctd.

↓

In the table below, indicate the average distance covered to fetch your household firewood over the years:

Period	**Average Distance (km)**
5-10 YEARS AGO	
1-5 YEARS AGO	
CURRENTLY	

6. How would you describe the distance covered to reach adequate source(s) of firewood in this area over the years?

About the same distance ☐
Increasing distance ☐
Decreasing distance ☐

7. List up to 4 factors that you reckon are responsible for the above phenomenon.

Factor 1---
Factor 2---
Factor 3---
Factor 4---